NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM 1226

ON THE INSTALLATION OF JET ENGINE NACELLES ON A WING

FOURTH PARTIAL REPORT: PRESSURE-DISTRIBUTION MEASUREMENTS ON A SWEPTBACK WING WITH JET ENGINE NACELLE

By R. Buschner

Translation of ZWB, Untersuchungen und Mitteilungen Nr. 3176, 1944

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SUMMARY

The present report, which deals with pressure-distribution measurements made on a sweptback wing with a jet engine nacelle, is similar to a report on pressure-distribution measurements on a rectangular wing with a jet engine nacelle (second partial report). Here, in investigations perliminary to high-speed measurements, as in the second partial report, useful arrangements and fillet designs have been discovered.

1. STATEMENT OF THE PROBLEM

The following arrangement was specified: a jet engine nacelle, the axis of which lies across a wing of constant chord at an oblique angle of 35°, at most. The nacelle length was twice the wing chord. The arrangement is to be regarded as half a sweptback wing, where an engine nacelle is mounted under the center of each wing. For reasons of experimental technique, only half a wing - therefore a portion of a yawed wing - is measured.

The subject to be investigated: where and under what conditions do velocity increases over the flight velocity appear with this arrangement in flight? How large are these excess velocities, can they be reduced by proper design?

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*"Der Anbau von TL-Triebwerken an den Tragflügel. 4. Teilbericht: Druckverteilungsmessungen an einem Pfeilflügel mit einem Triebwerk." Zentrale für wissenschaftliches Berichtswesen der Luftfahrtforschung des Generalluftzeugmeisters (ZWB) Berlin-Adlershof, Untersuchungen und Mitteilungen Nr. 3176, November 10, 1944.

As background, there are test results for rectangular and swept-back wings alone (fig. 1) and the pressure-distribution measurements on a rectangular wing with a jet engine nacelle (second partial report) (reference 1).

Results should be strived for which maintain the sweepback effect to its full extent. The sweepback effect and good Mach number behavior should result as an additional advantage, not at the price of disadvantages involved in the arrangement of sweptback wing and nacelle. The investigation avoids the theoretical treatment and is to be carried out experimentally.

Because of the significance of this investigation as a preliminary investigation for high-speed measurements to be undertaken later and in order to provide for comparisons with the investigation of the rectangular wing, this investigation is carried out also by use of wall pressure-distribution measurements. Particular attention should be given to the fillets between wing and nacelle where the largest pressure and velocity differences are to be expected. For correct arrangement and choice of fillet, no portion of the fairing should arrive at a critical velocity range at high flying speed sooner than the wing alone.

By installation of test stations in the fillet itself, it will be possible to evaluate - though only partly - how far the fillet selected is correct. For that reason, the wing itself and the nacelle are to be investigated as to the effects on them of the fillet selected. From the effect of the fillet on adjacent parts of the wing and engine, one may conclude the figure of merit of the fillet selected. The upper limit of the figure of merit attainable is specified by the wing alone; that is, the condition to strive for is that the increased velocities are nowhere higher than at the wing alone.

2. THE ARRANGEMENTS INVESTIGATED

The arrangements investigated differ from those described in the second partial report in the sweepback of the wing. The leading part of the wing lies on the right side of the jet engine macelle. This side, where the acute angle appears between the nacelle and the leading edge of the wing, is designated starboard in what follows. Correspondingly, the other side with the obtuse angle is called the port side. For the sake of completeness, the following data are repeated: $\Lambda = 3.2$, NACA profile 0 0012 1.140 in the direction of flow. The angle of attack was referred to the chord of the wing. In carrying out the experiments, the same point of view was held as for the rectangular wing: quick adaptation to new possibilities, thus the use of plasticene.

The susceptibility of many fillets to design change and the necessity of retaining them for comparison gave work to the tinsmith, too.

Tunnel 2 ($1m \times 1.5m$ open jet) with $V_0 = 25$ meters per second was used for the measurements. The Reynolds number referred to the chord of the wing in the direction of flow amounts to 0.6×10^6, which is to be borne in mind, especially at large angles of attack. In the numbering, arrangements 13 to 18 connect onto the series of experiments for the rectangular wings with nacelles. The numbering only gives the time sequence of carrying out the experiments. In the choice of an initial design the rectangular wing arrangement 6 was taken as a basis. The fillet used there had shown the best results for the rectangular wing and corresponded best, in regards to construction, to the requirements set forth. The sweepback arrangement 13 corresponding to this arrangement 6 was investigated first. Arrangements 14 to 15a are complementary arrangements to 13 with different wing fillets on the starboard side of the nacelle. In arrangements 16 and 17 the nacelle is suspended by a short and a longer strut underneath the wing. Lastly, arrangement 18 concerns the investigation of an asymmetric fairing of the fillet between wing and nacelle. The asymmetric fairing originated in the modification of the fillet of 13.

There was no fixed sequence for the arrangements investigated beforehand; rather, the arrangements investigated resulted automatically from the attempt to find an arrangement which corresponded to the conditions set forth. While the fillet from nacelle to wing and the forward position of the nacelle and, finally, the afterbody fairing were modified and investigated for a rectangular wing, those sorts of variations have been avoided for the sweptback wing and only the nacelle in mid-position was measured. As will be shown, the difficulties characteristic of the sweptback wing are already readily apparent with this arrangement. If these can be mastered, it will be possible to design other suitable arrangements also by using the knowledge gained with the rectangular wing.

3. RESULTS

(a) Application of the Results Obtained with the Rectangular Wing

Arrangement 13, the first to be investigated, is copied directly from the rectangular wing arrangement and is to be seen in detail in figure 2. The test results are so plotted in the figures, that the measured pressures are to be found directly below the test stations indicated in the over-all sketch. The measurements (fig. 3) illustrate, for one thing, the effect of the angle of attack α for an angle of yaw $\beta = 0$; for another thing, they show the effect of a change in the

angle of yaw, β, at various fixed angles of attack (figs. 4 to 6). The fundamental difficulties which appear in the installation of TL-nacelles on the sweptback wing are seen in the comparison graphs for arrangements 6 and 13 in figures 7, 8, and 9.

Fundamentally, starboard and port sides are different. As an effect of the sweepback, the suction peak becomes larger on the starboard side of the upper surface of the sweptback wing than for the rectangular wing, although the sweptback wing alone has smaller low pressures than the rectangular wing alone (fig. 1). This is noticeable in high-speed flight at small values of c_a in an increase of the excess speeds, through which the improvement desired is lost, and at large c_a values in earlier breakaway of the flow. On the under side of the wing, too, the excess velocities are increased considerably to starboard. A very flat minimum arises that might become dangerous at high Mach numbers.

These phenomena observed on the starboard side are not observed in this degree on the port side in the region of the nose of the wing. On the upper surface of the wing and on the under side the values are better than for the rectangular wing. Deteriorations, which are considerable, appear on the trailing portion of the wing. More fundamental reasons for this behavior shall be discussed in connection with arrangement 18. While conditions are shown in the first figures for which the through flow was completely throttled, as a result of which extreme loads arise at the nacelle intake, figures 10 to 13 show measurements for a through flow which corresponds to high-speed flight. It can be determined that the effect of the through flow on the fillet of interest between nacelle and wing is very small. On that account the following arrangements were investigated with zero through flow.

As a result the fillet of arrangement 13 appears useless. The application of a cowling design proven good for a rectangular wing to a sweptback wing arrangement is, therefore, not permissible. However, since a complete fairing between nacelle and wing is required most of the time for construction reasons, an attempt was made, first to improve the starboard side of arrangement 13.

(b) Changes in the Fairing on the Starboard Side

Since good results are obtained for a rectangular wing by constructing a large shoulder cowling, corresponding measures were also attempted with a sweptback wing. (See arrangements 14a to 14e and 15a to 15b; figs. 14 to 18.) It was well known by the author that a shoulder on a rectangular wing is synonymous with a sweepback, while in the case of a sweptback wing the sweepback is exactly cancelled by it, since the leading edge in this region runs perpendicular to the direction of flight.

The remaining possibilities are an increase of the chord of the wing in this region as well as changes of the profile which concern the radius of the nose (arrangement 15a) and the design (for example, a hinged nose, arrangement 14c). However, a fundamental solution of the difficulties appearing on the starboard was not obtained. The improvements made are always limited only to a small range of the angle of attack. In arrangement 15 the construction of a split nose flap according to Krüger (reference 2) led to good results (fig. 18).

(c) Modification of the Fillet

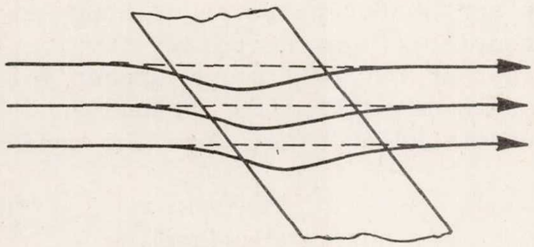
It is to be assumed that part of the difficulties that appear depend on the fact that the complete fillet between nacelle and wing has a large lateral surface which sets up a large hindrance to the flow. Therefore, the fillet has been left out completely in arrangements 16 and 17 and the rotationally symmetrical nacelle has been suspended from profiled struts (fig. 19). The case has no practical significance and only serves for purposes of comparison. It is recognized from the results (figs. 20 to 27) that conditions at the wing actually become better but that large excess velocities appear at the strut, as a result of which this arrangement, like the corresponding one for the rectangular wing, does not appear useful.

(d) Asymmetric Cowling

The investigations up until now did not yield any useful designs. To get on, the cavitation method of Reichardt (reference 3) was turned to in the hope of finding a way of improving the existing arrangement by observation of the natural flow. Reichardt specifies an increased pressure contour. With flow in the cavitation region, a bubble is formed in which the pressures are equal to those of the surrounding contours. In the present case, a ring of increased pressure contours occurred at the nacelle intake and the leading-edge of the sweptback wing. The bubbles expanding for the nacelle and wing separately showed an unusual asymmetry in the fillet from wing to nacelle. In the forward part of the starboard side of the fillet an impressed groove forms. The picture presented to the eye gives the impression that space was left on the starboard side of the flow for ample flow on the under side of the wing. Admittedly, the method only affords observations of flow phenomena at first, but it is convincing in its clarity.

These observations of the flow were a worth-while aid. The phenomena observed up to the present time can now be interpreted physically, too.

In addition to the flow parallel to the longitudinal nacelle axis, a secondary flow forms with velocity components parallel to the leading edge of the wing. To understand the process somewhat better, in the case of a positively sweptback wing consider a few adjacent wing cross-sections and the pressure distribution over them. Disregarding the fact that over the wing span there exists a falling off of pressure outward already, the variation by degrees of the wing cross sections in the case of a sweptback wing has the same effect as a variation by degrees of the pressure distribution over like profiles. Thereby, in the forward portion of the wing, pressures falling off outward come to lie next to one another, which cause an acceleration of the air outward, that is, in the direction of the trailing wing; a secondary flow arises, approximately parallel to the leading edge of the wing. In the trailing portion of the wing, the secondary flow moves from the trailing to the leading side, so that altogether the flow has the variation pointed out in the sketch below.



If a hindrance is placed in this secondary flow, as for instance the nacelle in the present experimental arrangement, which prevents a complete development of the secondary flow, additional excess velocities are obtained which occur in the present case on the starboard side in the forward portion of the wing, on the port side in the trailing portion of the wing. These phenomena are to be clearly recognized with arrangement 13 and with the strut arrangements 16 and 17. Besides, there is joined to this the deflected flow around the nacelle, by which conditions are made still worse.

These are the same arguments which are applied by Professor Quick, also, in the installation of a fuselage on a sweptback wing. The knowledge obtained is made use of in fashioning the fillet of arrangement 18, chiefly on the starboard side (figs. 28 and 37). The test results seem to confirm the suppositions made. A substantial improvement of the starboard side over arrangement 13 and, also, over the rectangular-wing arrangement 6 is obtained. The excess velocities are clearly reduced (figs. 34 to 36).

It appears that the flow in the hollow starboard side underneath the wing is diverted better than by the raised side starboard of the strut (fig. 33), by way of comparison. Thus the deflection of the flow remains in the same direction. The accelerations appearing cease. Naturally, arrangement 18 is not the best. However, it is permissible to expect further improvements on the basis of results up to the present. Arrangement 18 still has the faults of arrangement 13 on the port side. There a velocity component inward appears. This would have to be met with a groove sufficient at this position. Also on the underside of the wing on the starboard side, improvement may certainly be gained by a grooving and also by a change in the radius of the nose. A new improved fillet will take into account the knowledge acquired.

The results still are not in.

4. SUMMARY

The existing measurements were taken on a sweptback arrangement with special consideration of the fillet design from wing to nacelle. The initial form selected, which had shown the best results for the rectangular wing, proved useless for application to the sweptback wing in a noncentral arrangement. Difficulties appeared with it in the treatment of fillet designs, which are to be characterized as typical for the prescribed sweptback wing arrangement. They result from the secondary flow, effected through the sweepback on the fillet, which must be taken into account in the choice of a design. A more suitable design was measured. It is asymmetrical and hollow in a manner adapted to the secondary flow. The design created gives an improvement in the results by a sweepback arrangement over the corresponding rectangular-wing arrangement described elsewhere.

According to the results obtained, the method seems correct for finding fully developed designs for a sweptback-wing arrangement. The essential difficulties are known. From case to case, however, the individual nature of the problem set forth will have to be considered accurately. The results are not confirmed at high Mach numbers. To check the correctness must remain the subject of a newer experiment.

Translated by Dave Feingold
National Advisory Committee
for Aeronautics

REFERENCES

1. Teilbericht 2: Der Anbau von TL-Triebwerken an den Tragflügel. Soon to be published as a UM.

2. Krüger: Systematische Windkanalmessungen an einem Laminarflügel mit Nasenklappe. FB 1948.

3. Reichardt: Kavitationsmodell zur Ermittlung druckkonstanter Begrenzungsflächen für rotationssymmetrische Durchläufgeräte. UM 6606.

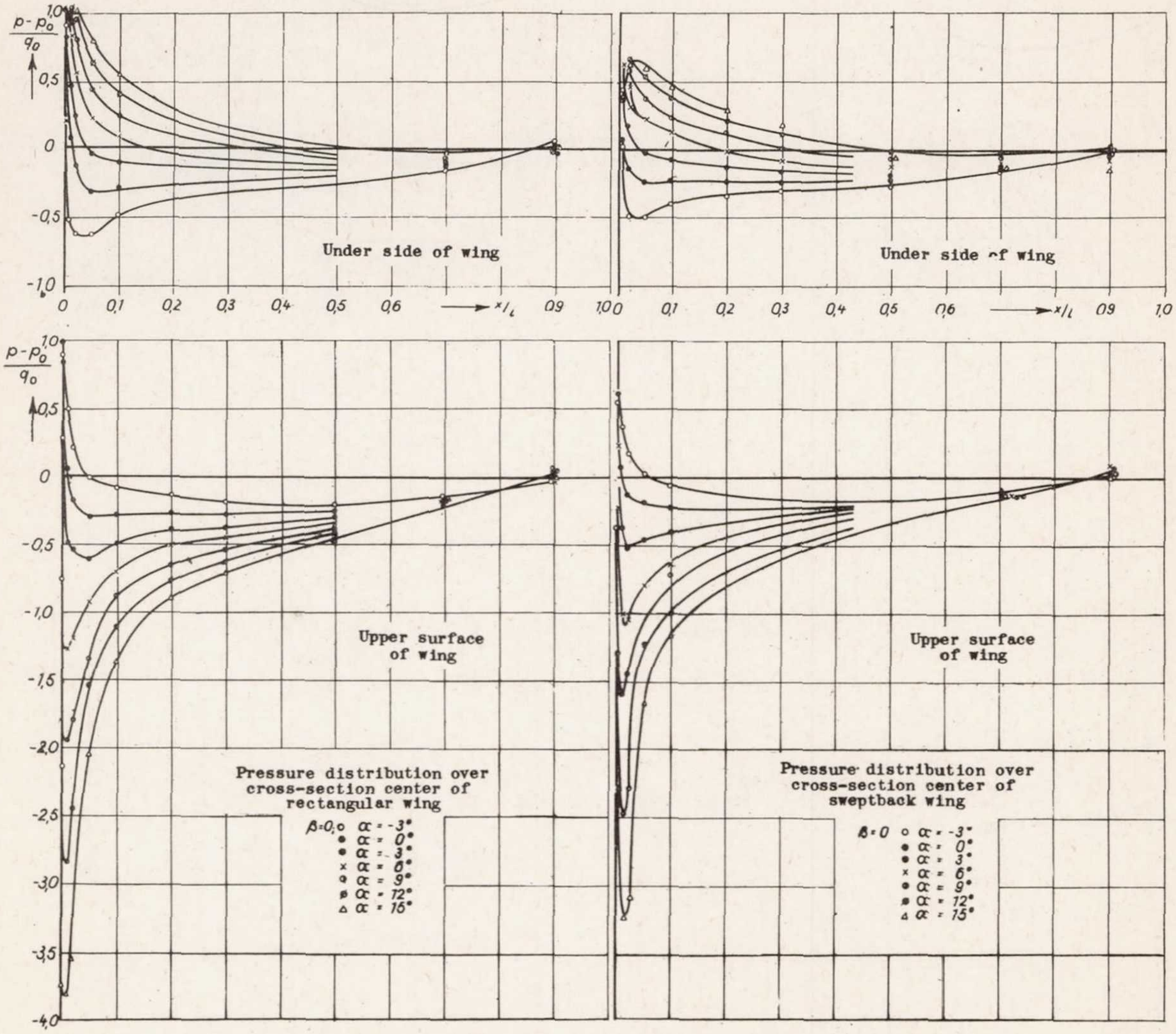


Figure 1.- Pressure distribution for sweptback and rectangular wing; $\beta = 0^{\circ}$.

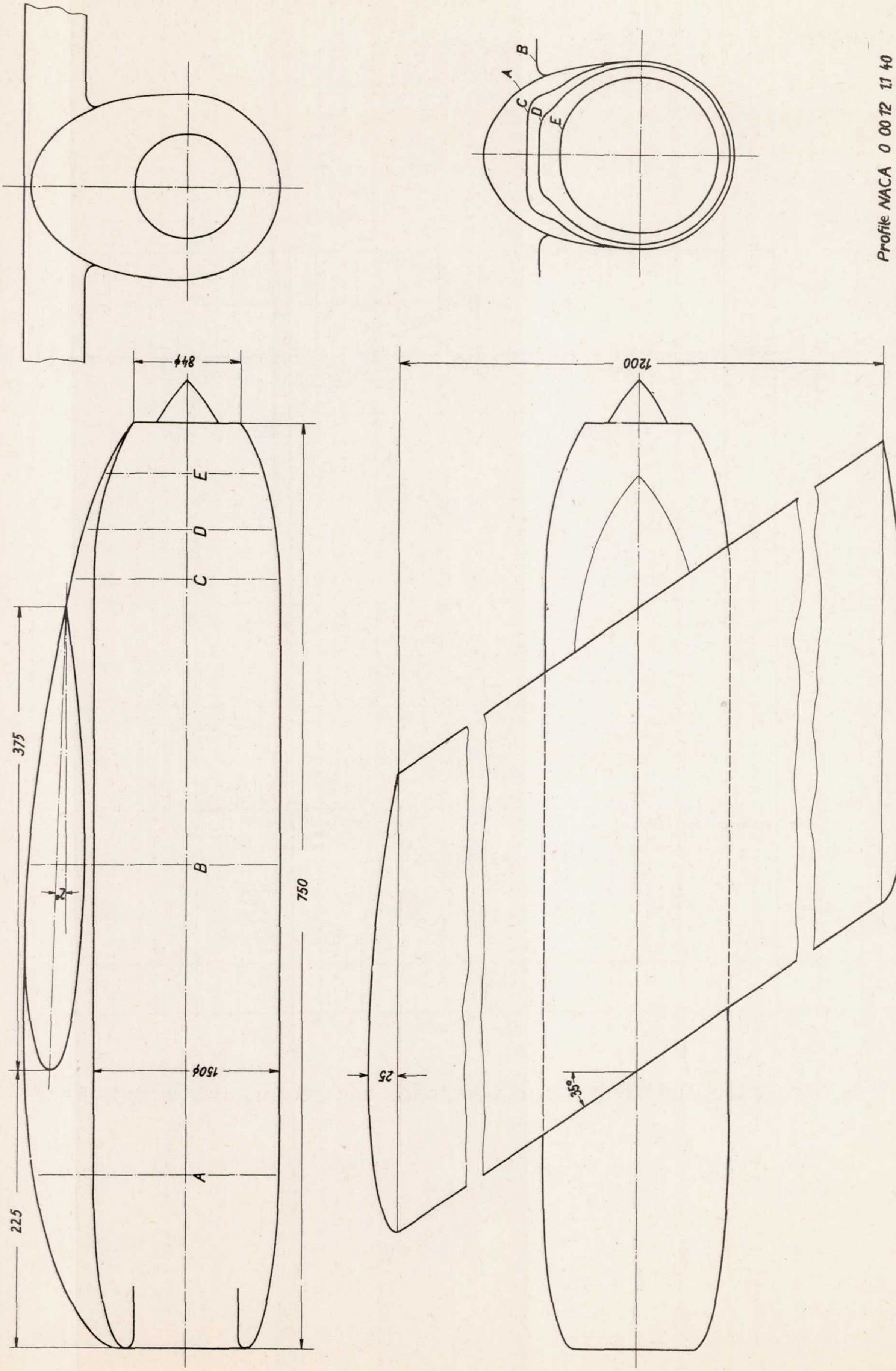


Figure 2.- Arrangement 13; over-all view.

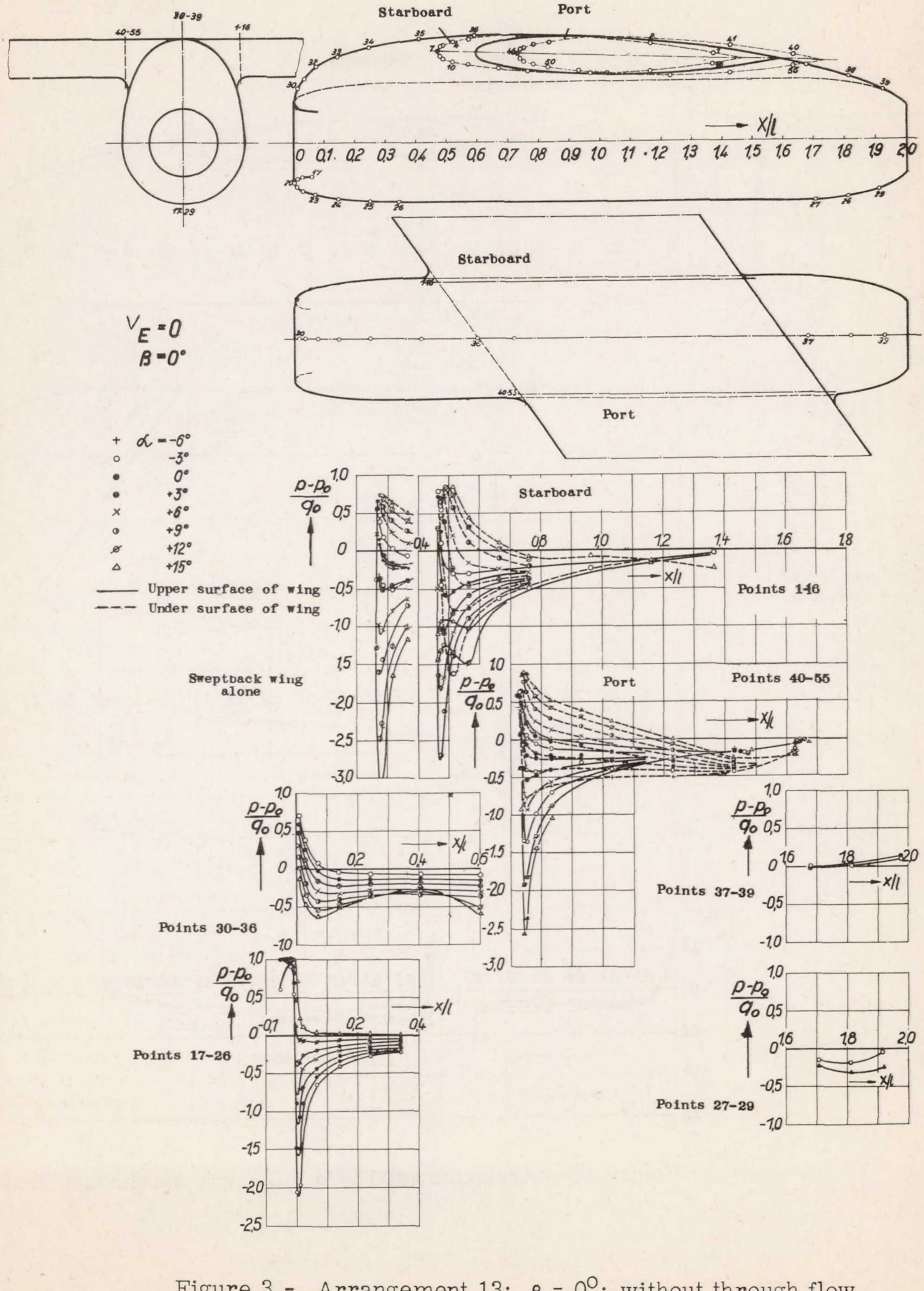


Figure 3.- Arrangement 13; $\beta = 0^{\circ}$; without through flow.

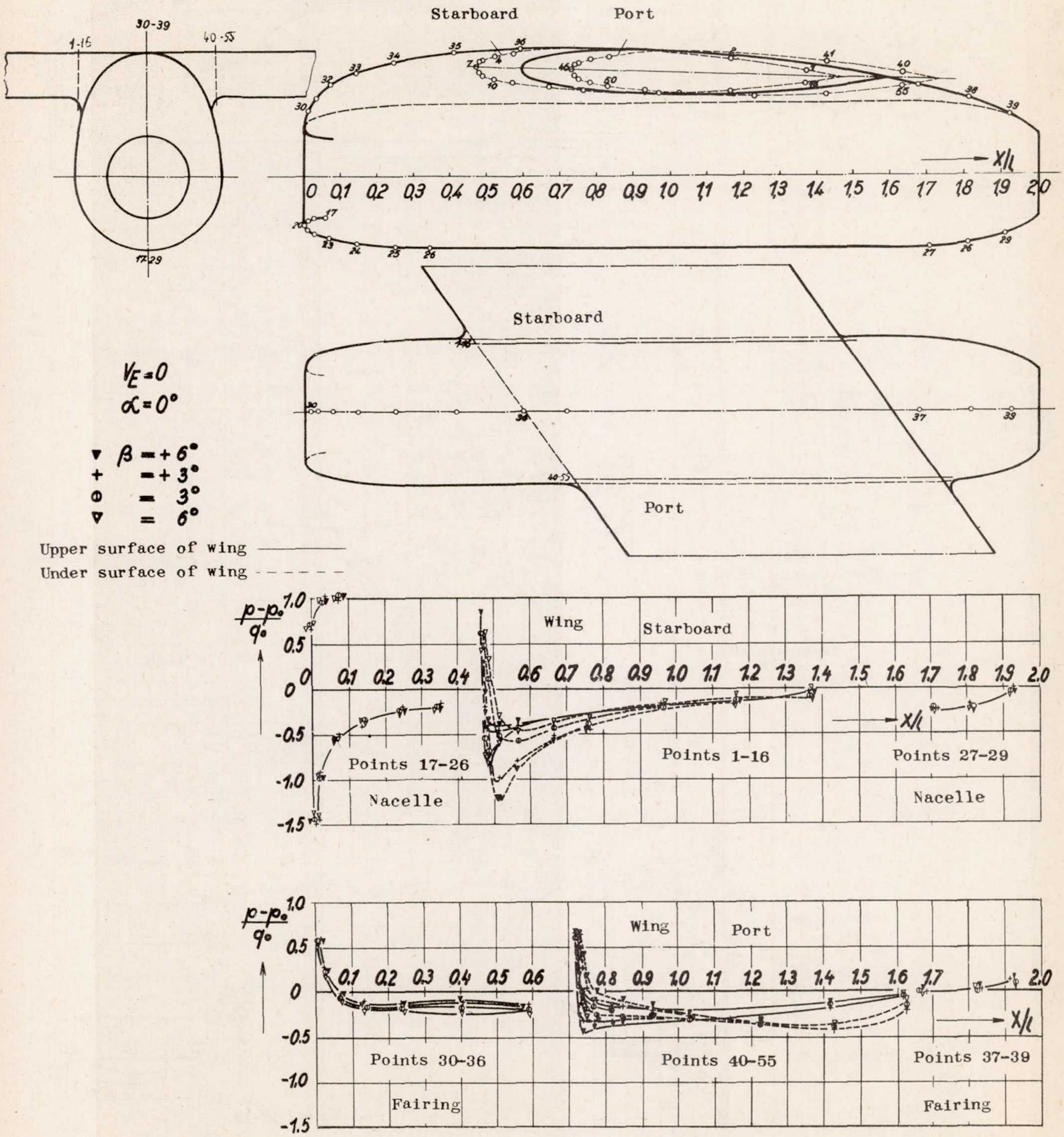


Figure 4.- Arrangement 13; $\alpha = 0^{\circ}$; without through flow.

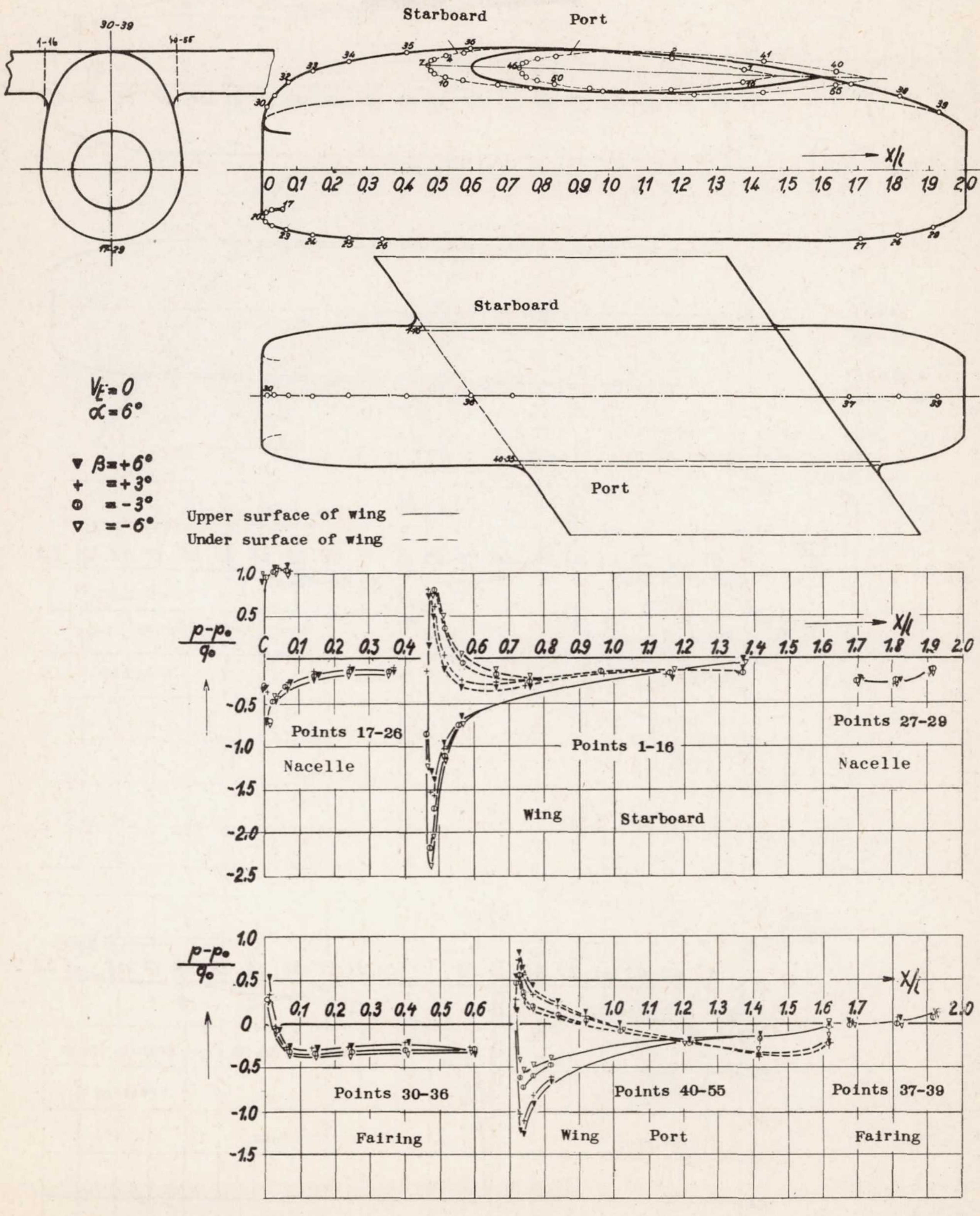


Figure 5.- Arrangement 13; $\alpha = 6^{\circ}$; without through flow.

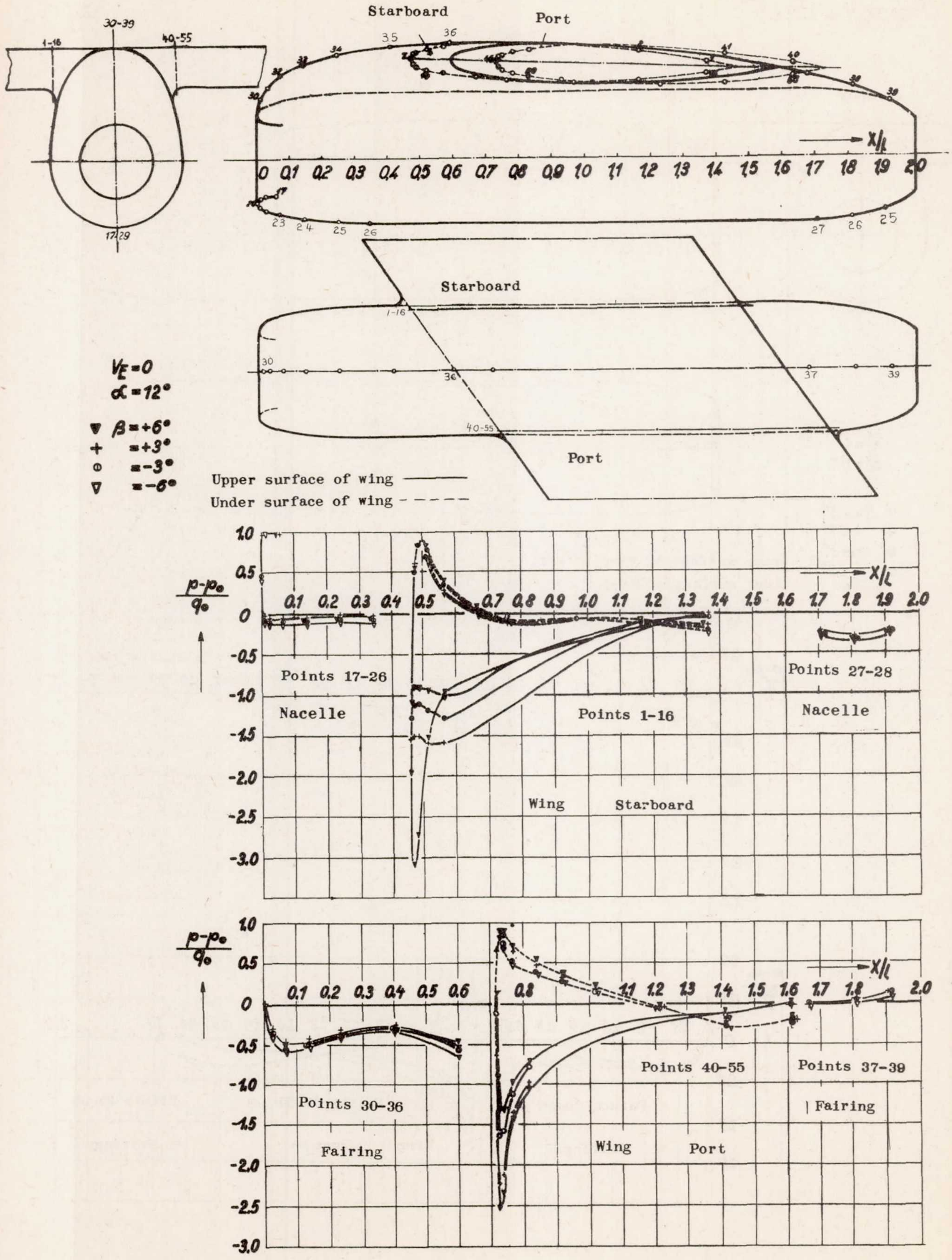


Figure 6.- Arrangement 13; $\alpha = 12^{\circ}$; without through flow.

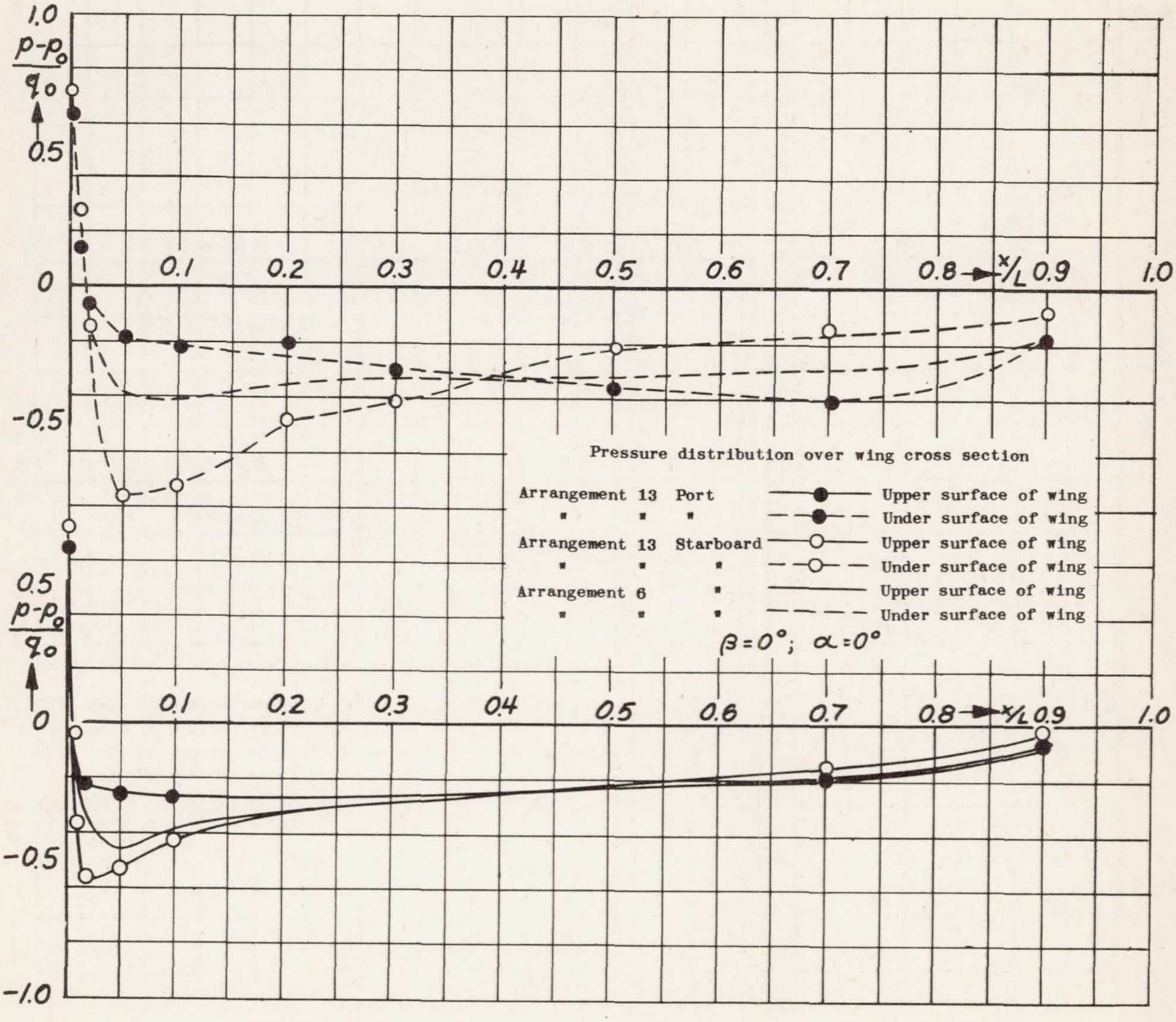


Figure 7.- Arrangement 13 and arrangement 6; through flow; $\alpha = 0^{\circ}$.
(Comparison)

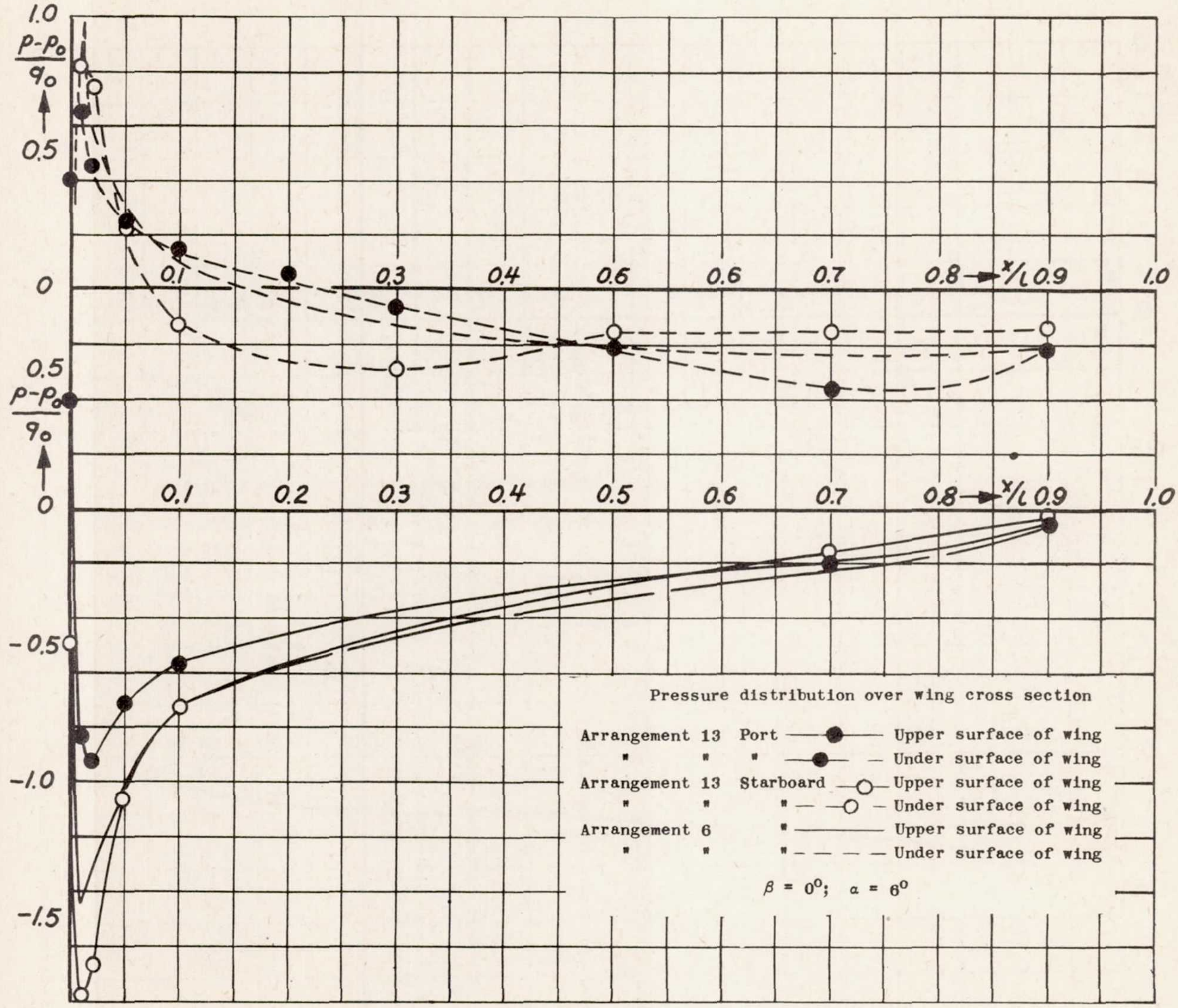


Figure 8.- Arrangement 13 and arrangement 6; through flow; $\alpha = 6^{\circ}$. (Comparison)

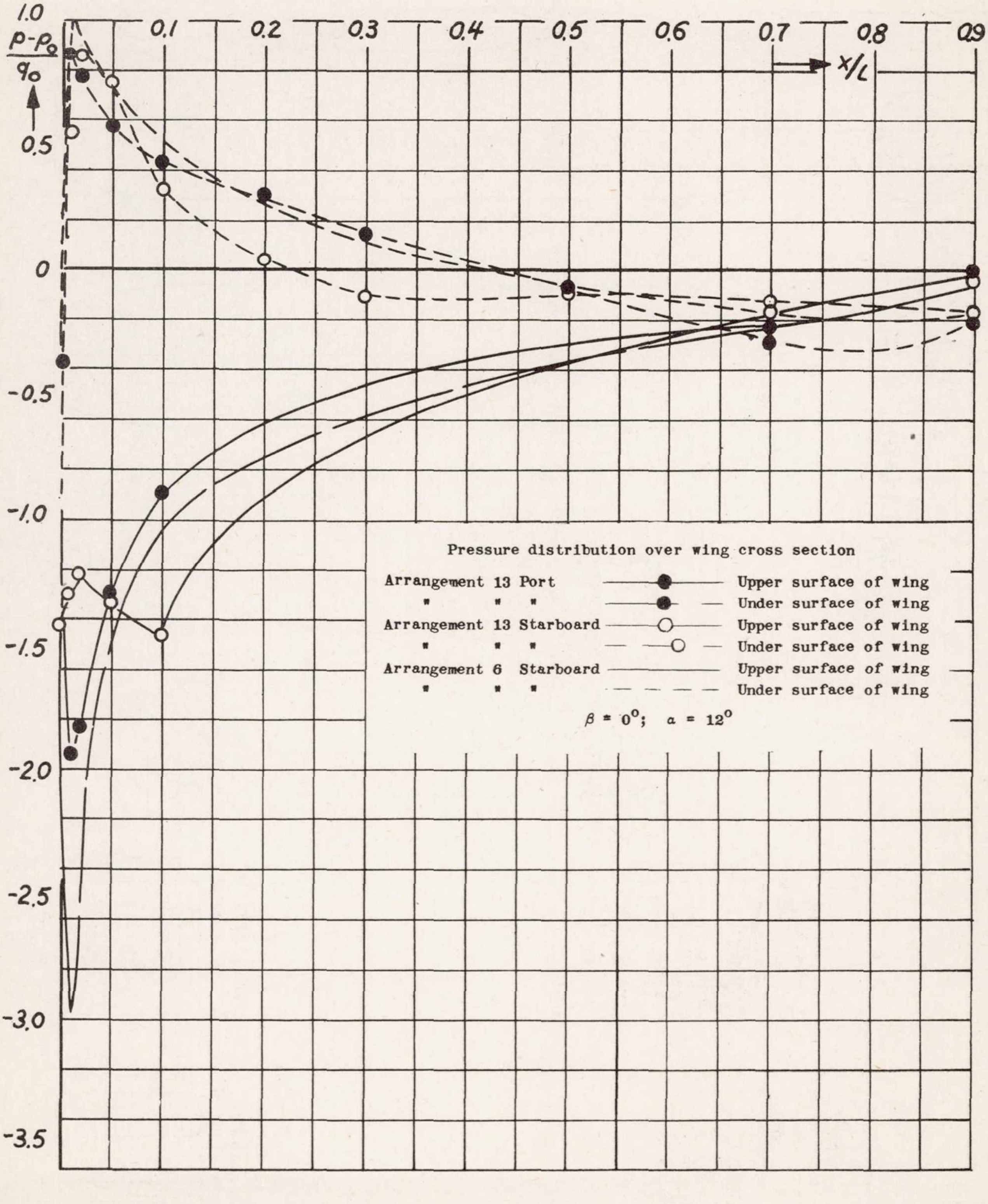


Figure 9.- Arrangement 13 and arrangement 6; through flow; $\alpha = 12^{\circ}$. (Comparison)

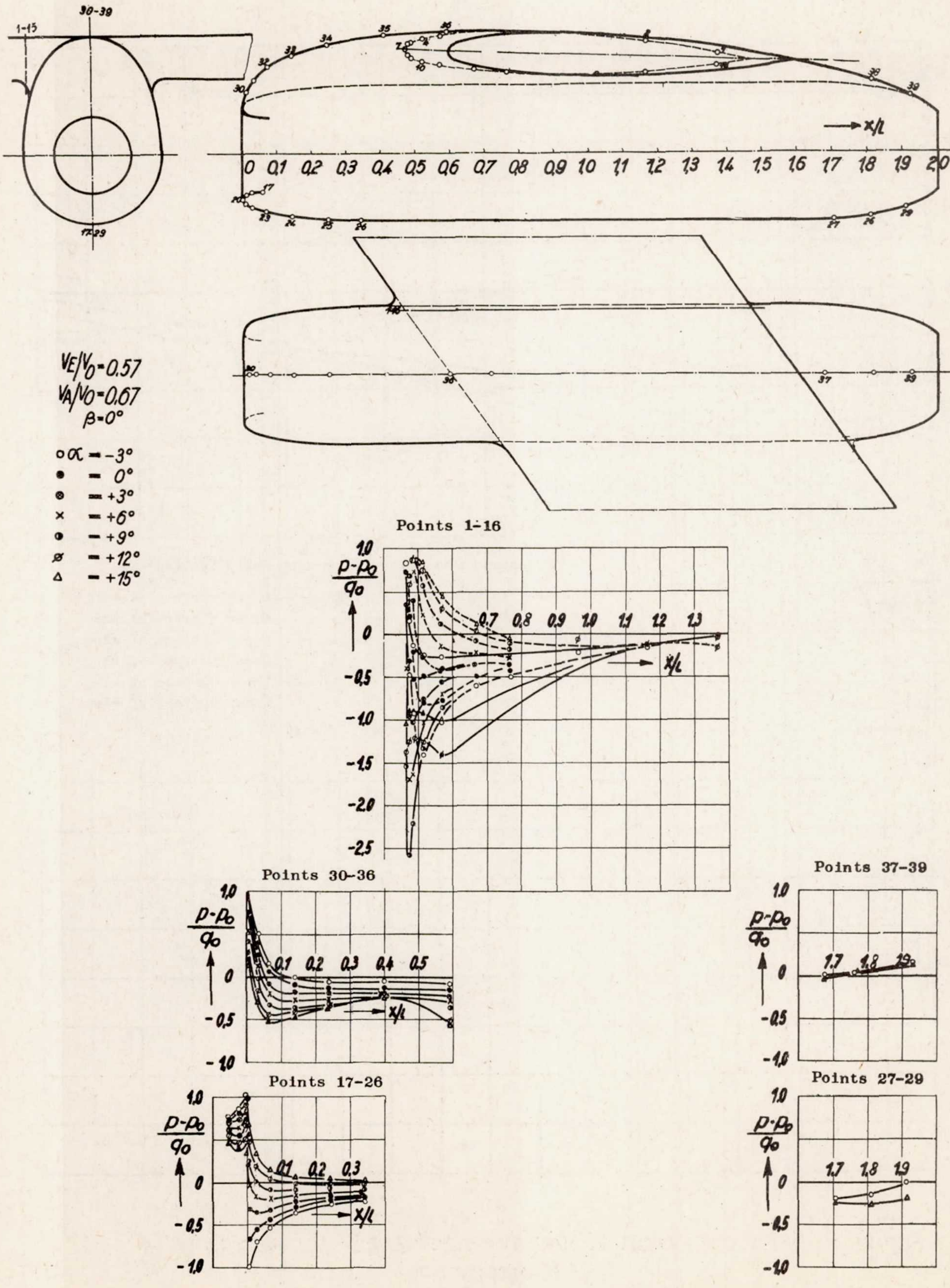


Figure 10.- Arrangement 13; $\beta = 0^{\circ}$; with through flow.

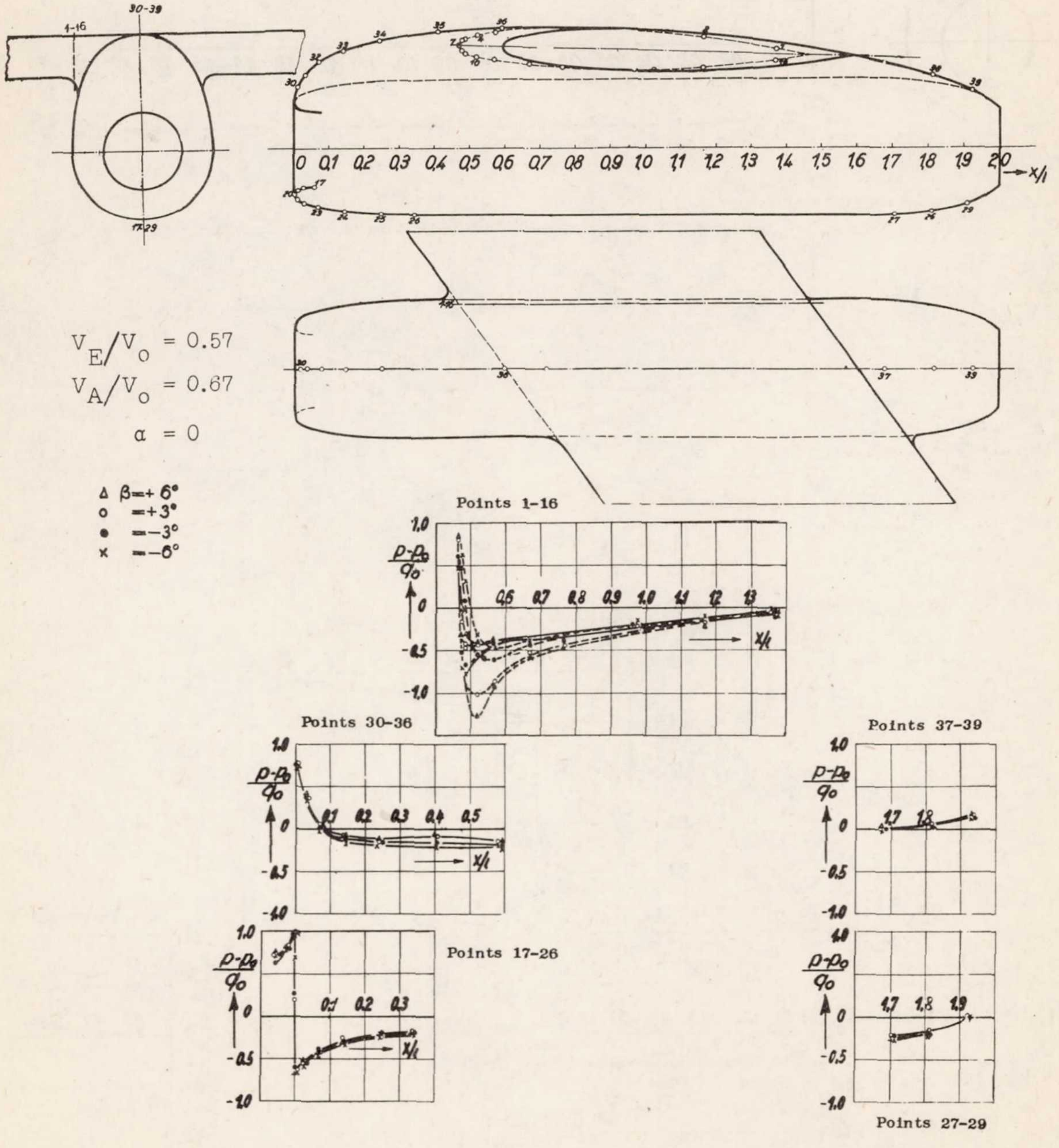


Figure 11.- Arrangement 13; $\alpha = 0^\circ$; nacelle with through flow.

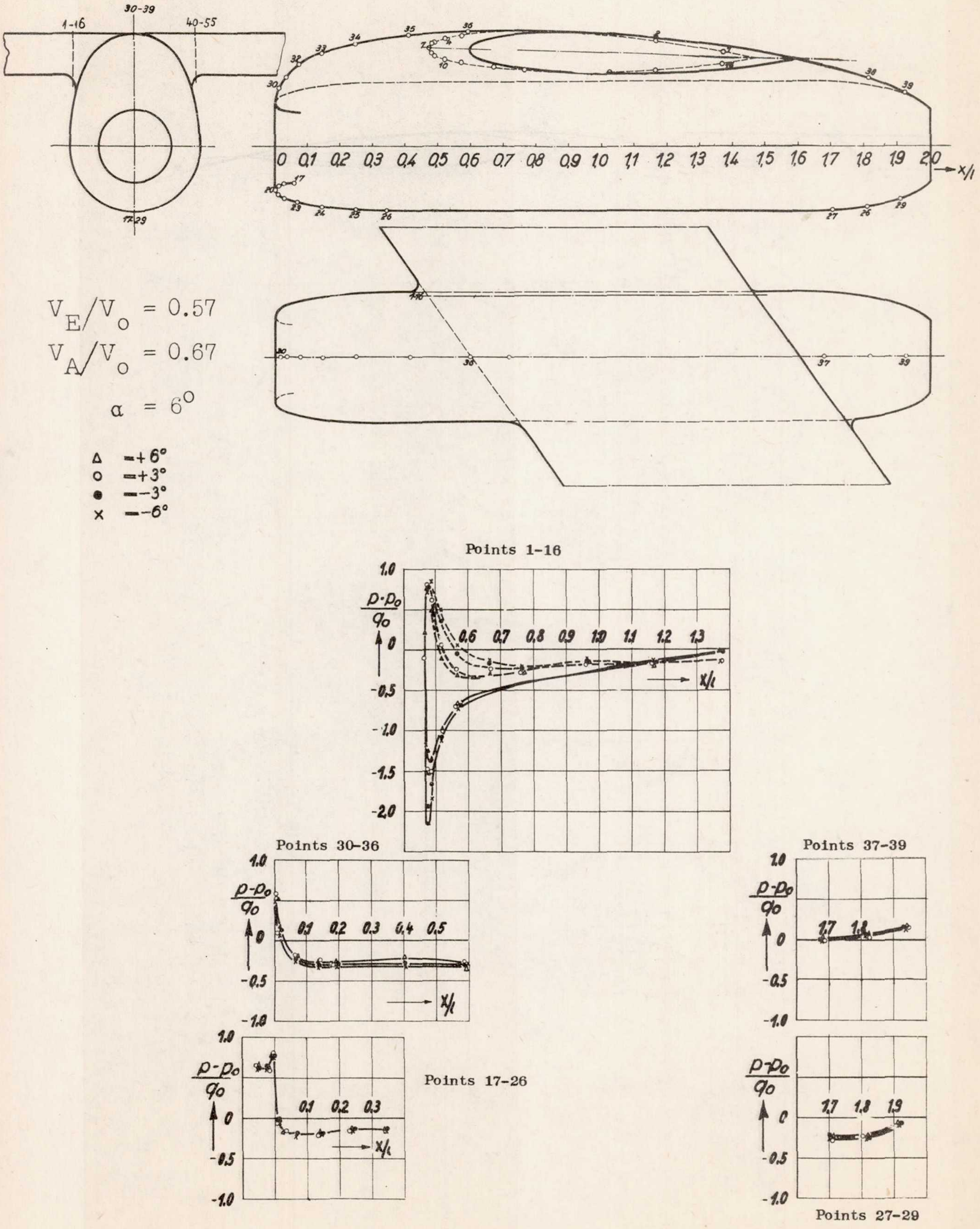


Figure 12.- Arrangement 13; $\alpha = 6^o$; nacelle with through flow.

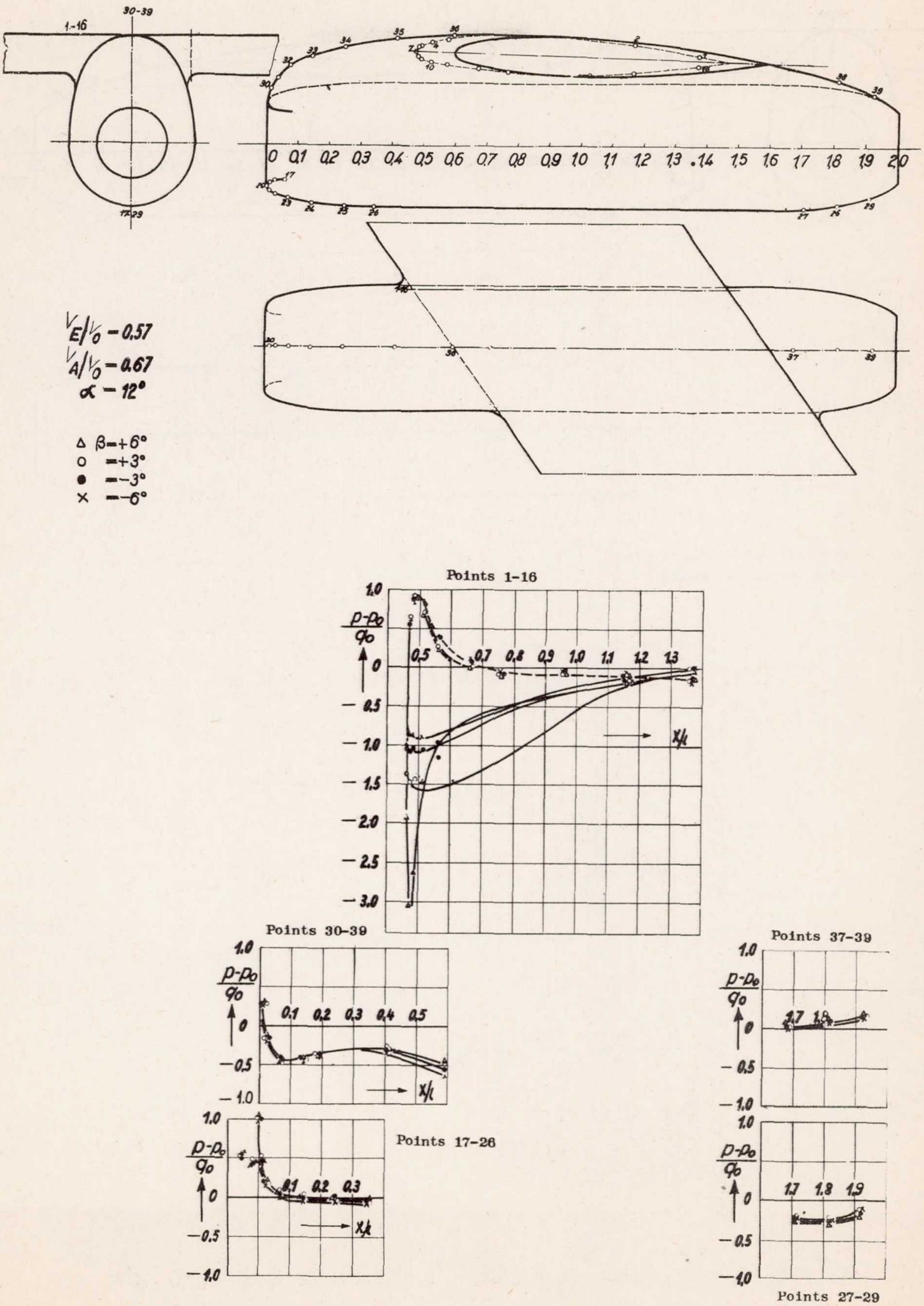


Figure 13.- Arrangement 13; $\alpha = 12^{\circ}$; with through flow.

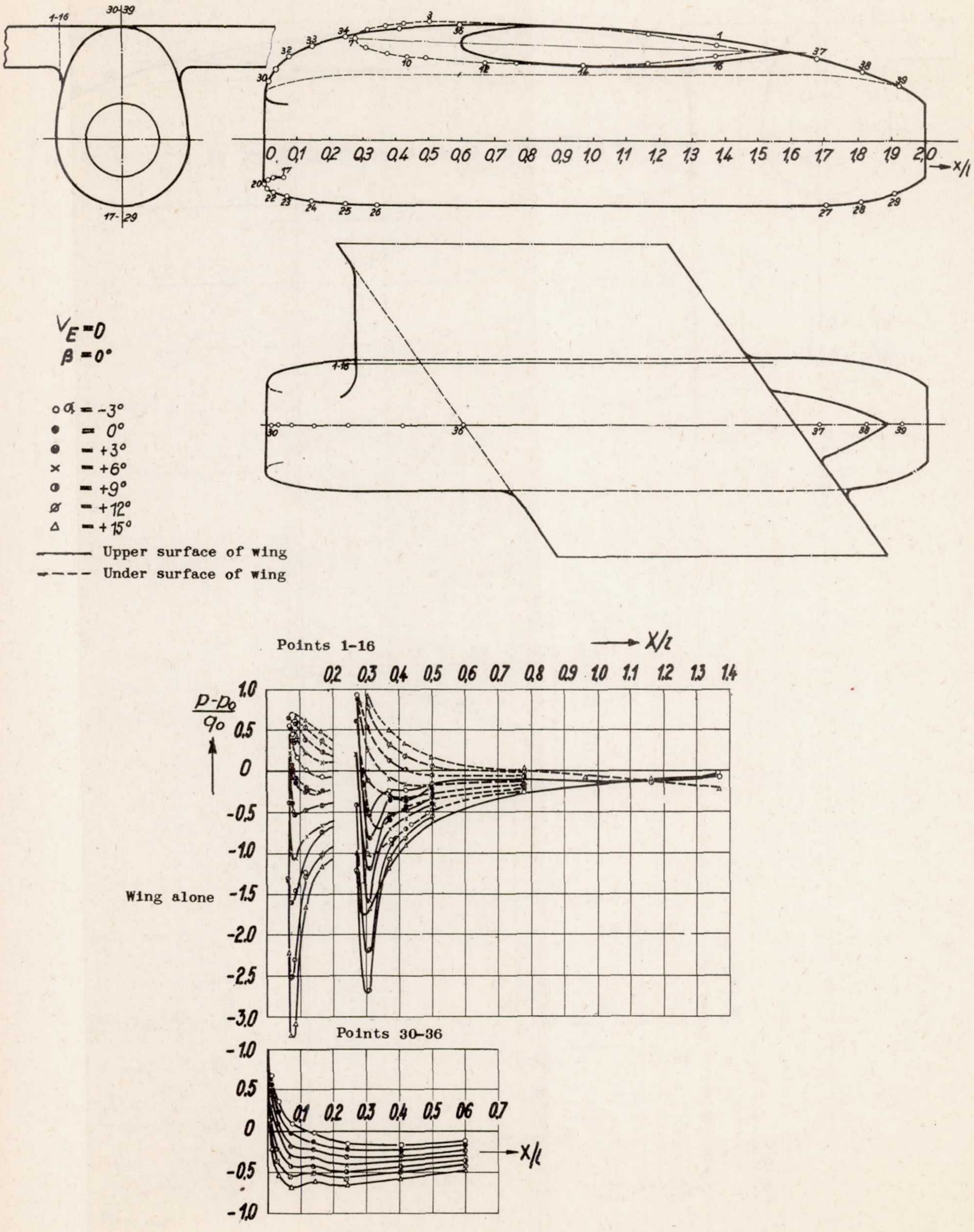


Figure 14.- Arrangement 14a; β = 0°; without through flow.

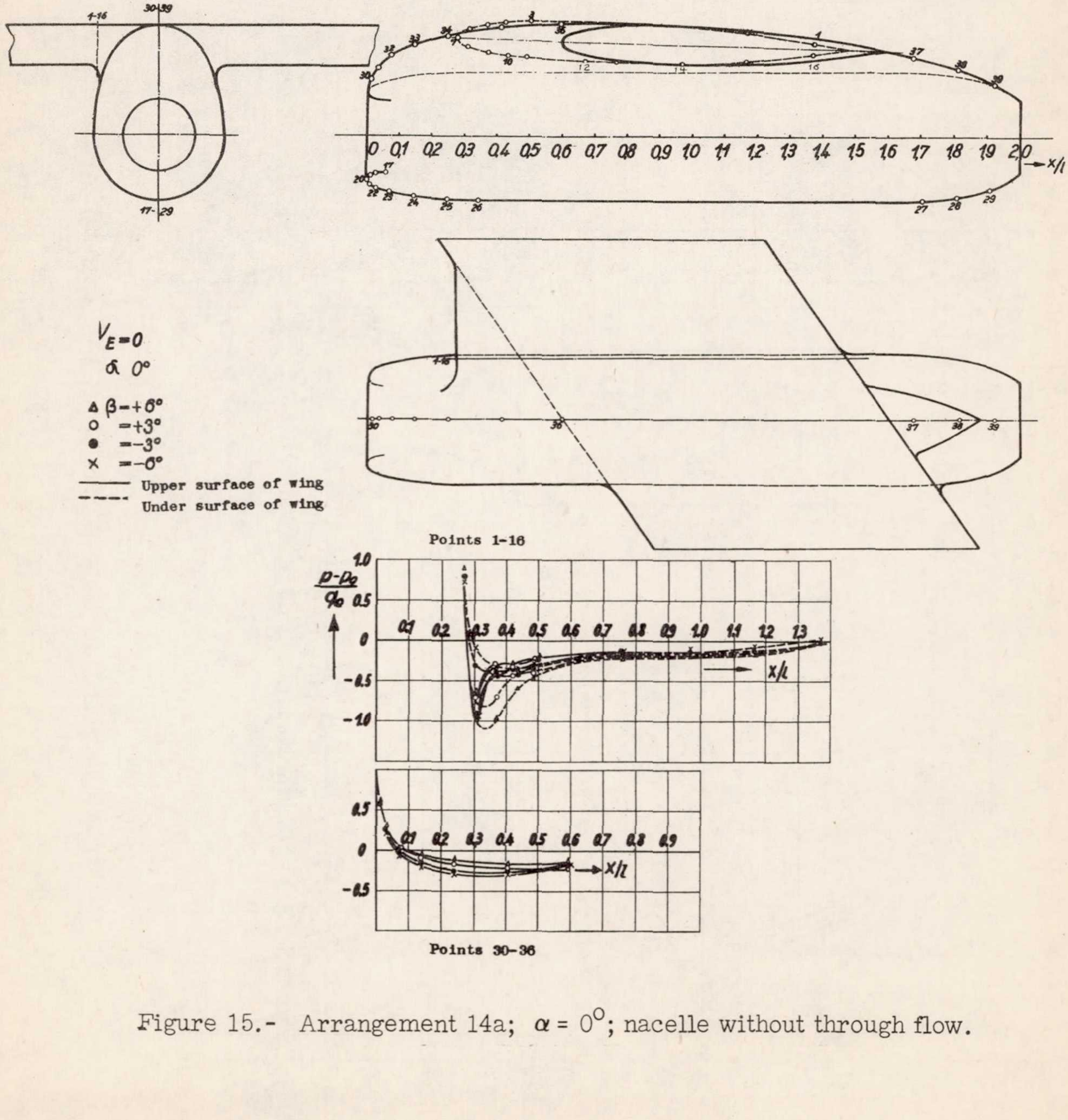


Figure 15.- Arrangement 14a; $\alpha = 0^{\circ}$; nacelle without through flow.

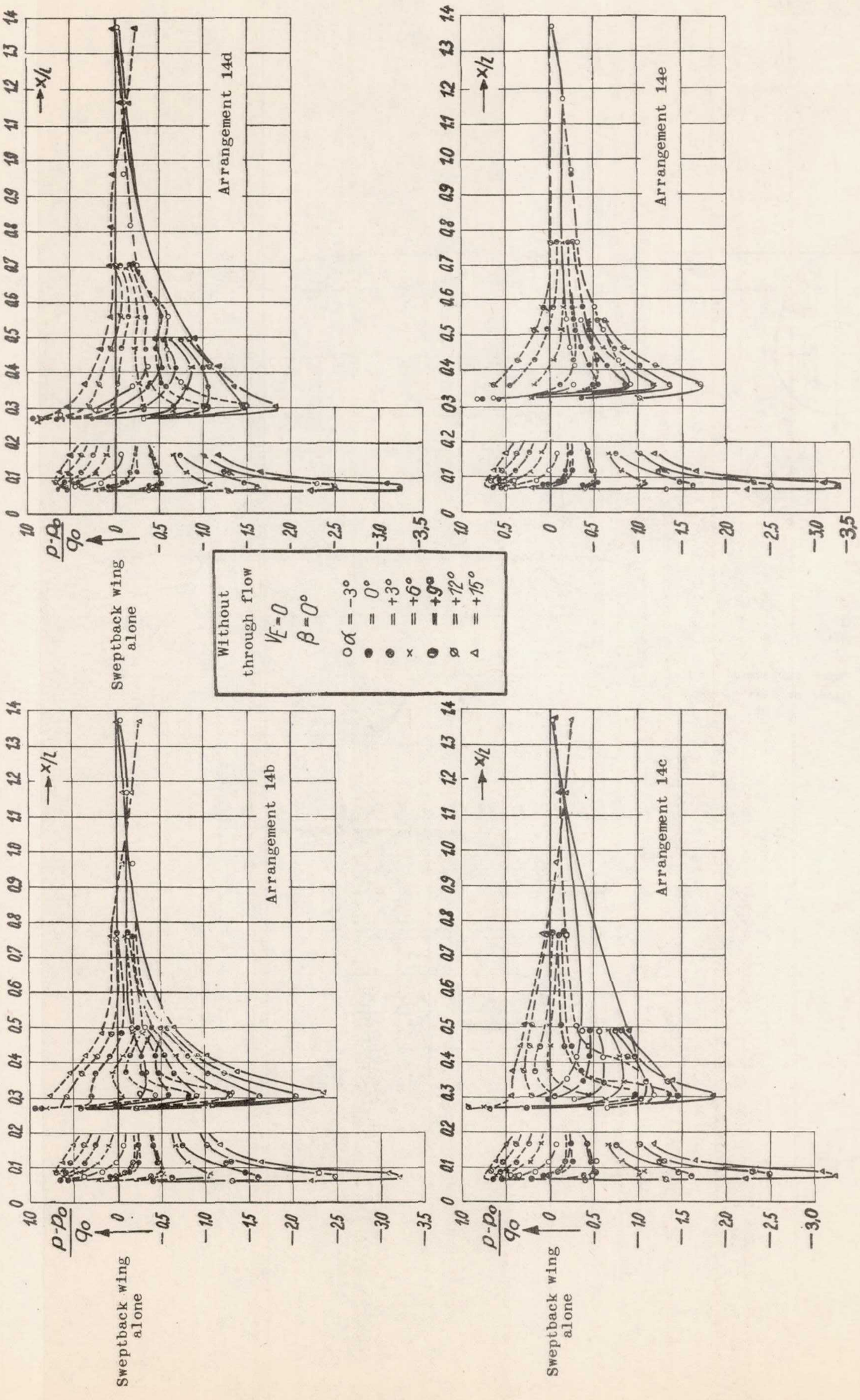


Figure 16.- Arrangement 14b-e; $\beta = 0^{\circ}$ without through flow.

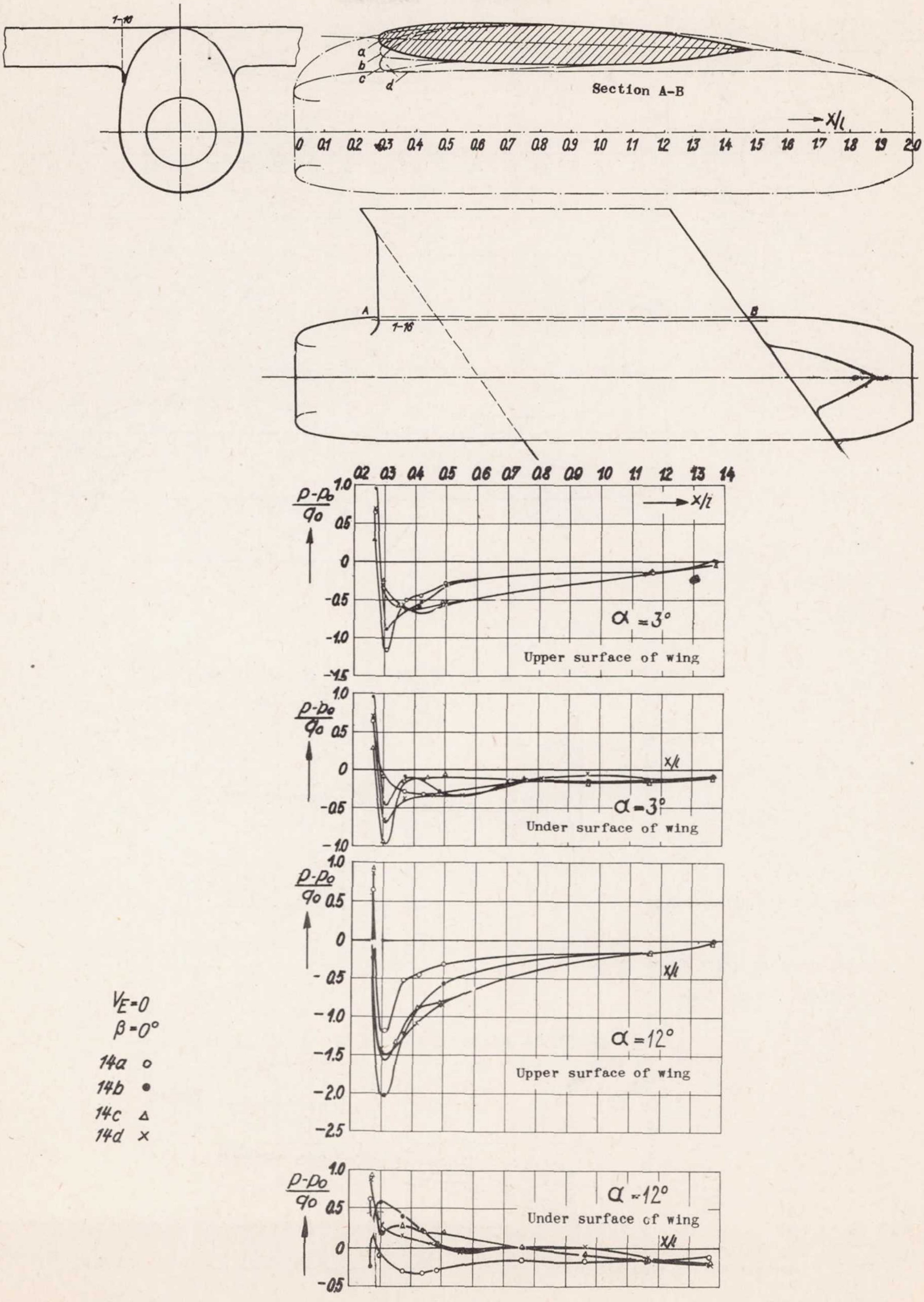


Figure 17.- Arrangement 14a-d; $\beta = 0^\circ$ without through flow (comparison).

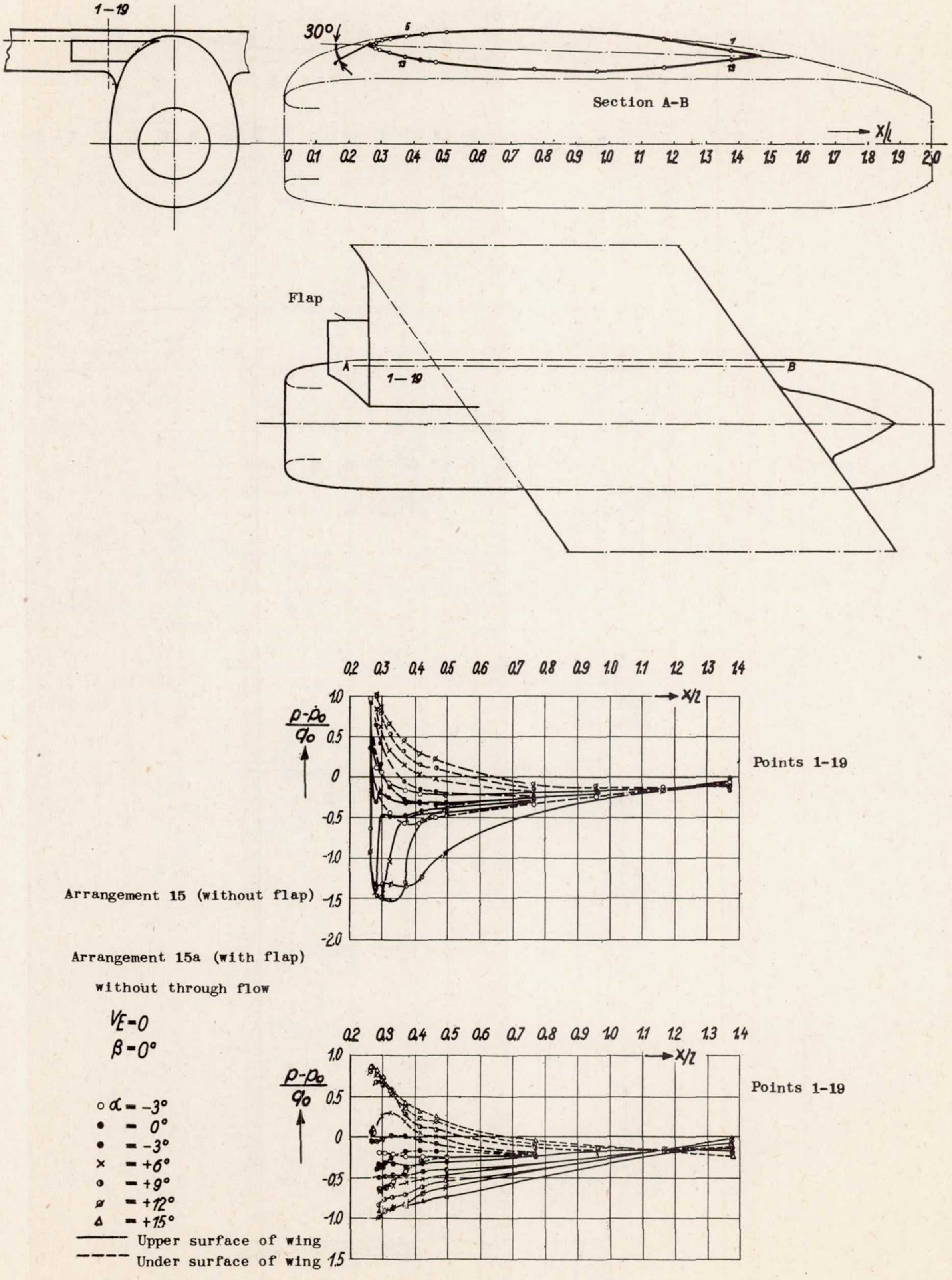


Figure 18.- Arrangement 15, 15a; $\beta = 0^{\circ}$; without through flow.

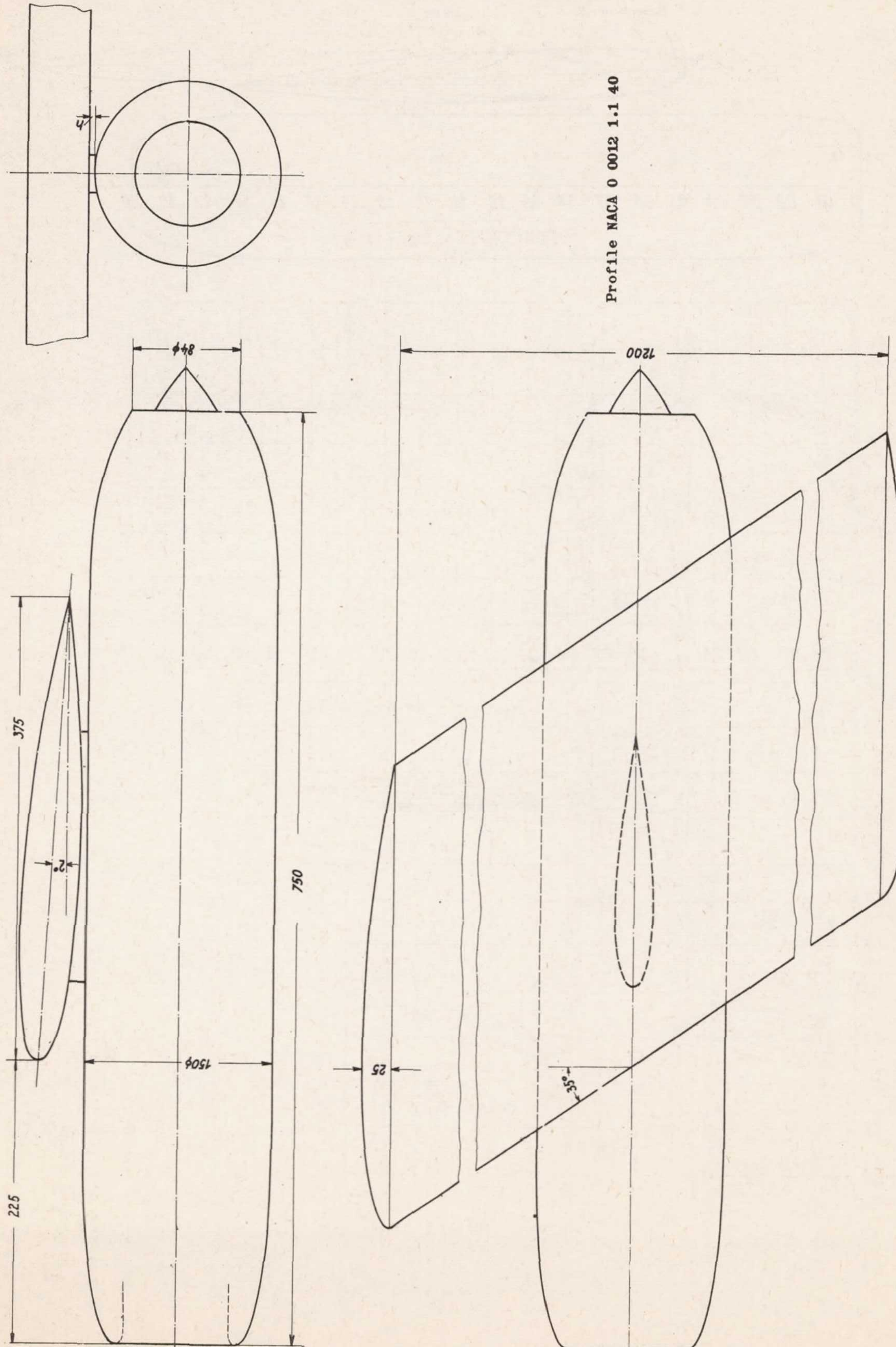


Figure 19.- Arrangement 16, 17; over-all drawing. (h = 10 mm)

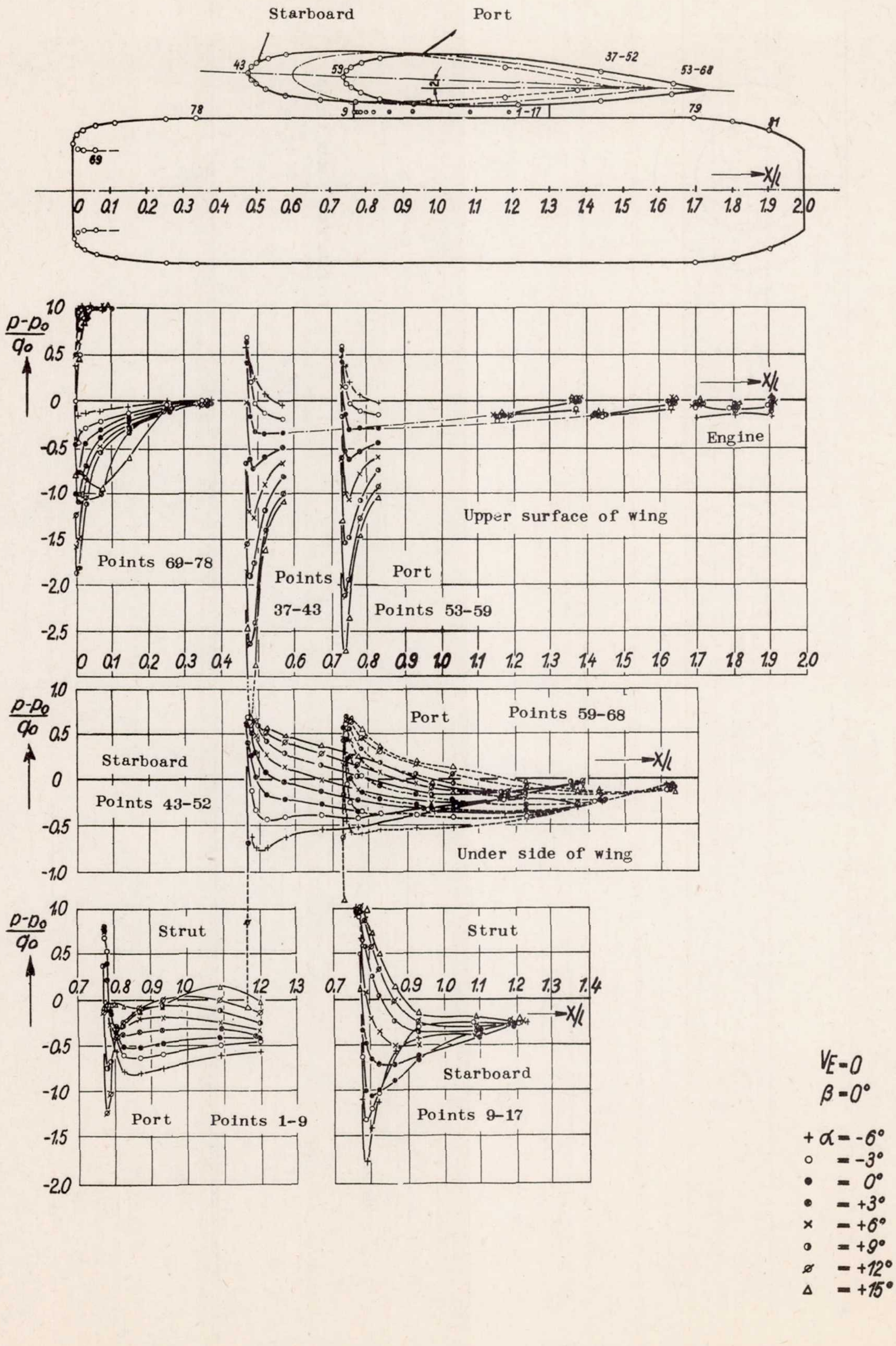


Figure 20.- Arrangement 16; $\beta = 0^{\circ}$; without through flow.

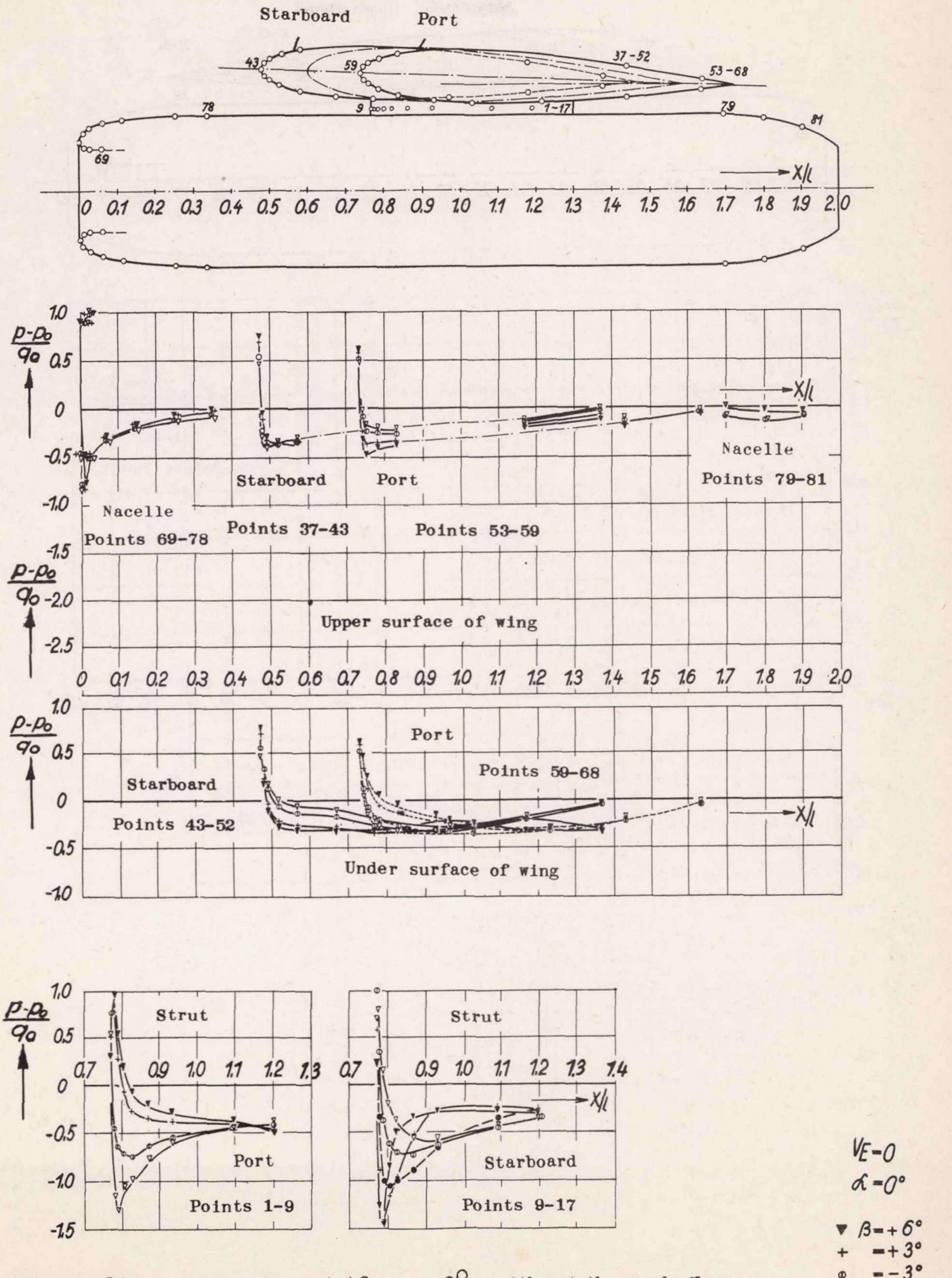


Figure 21.- Arrangement 16; $\alpha = 0^{\circ}$; without through flow.

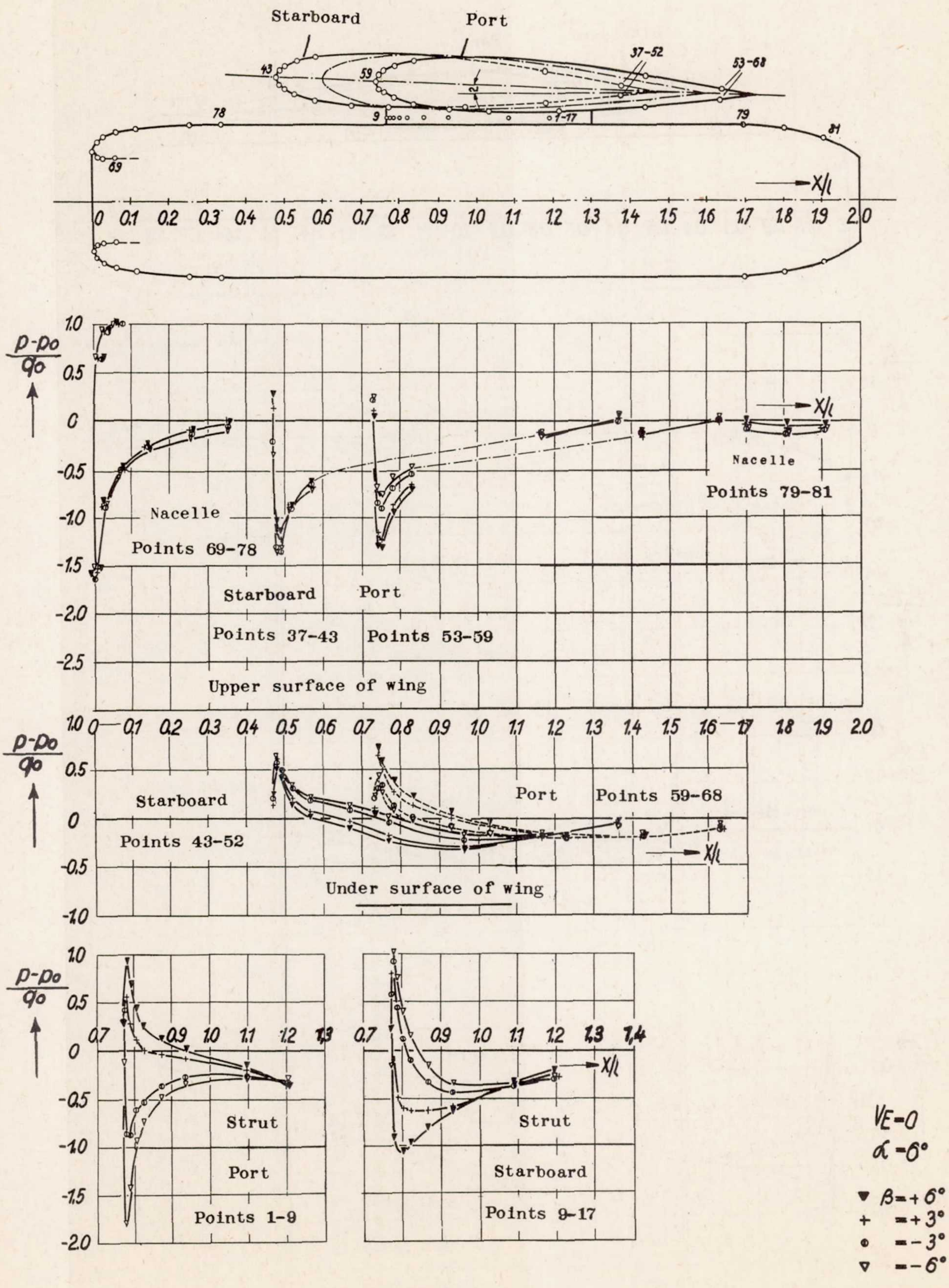


Figure 22.- Arrangement 16; α = 6°; without through flow.

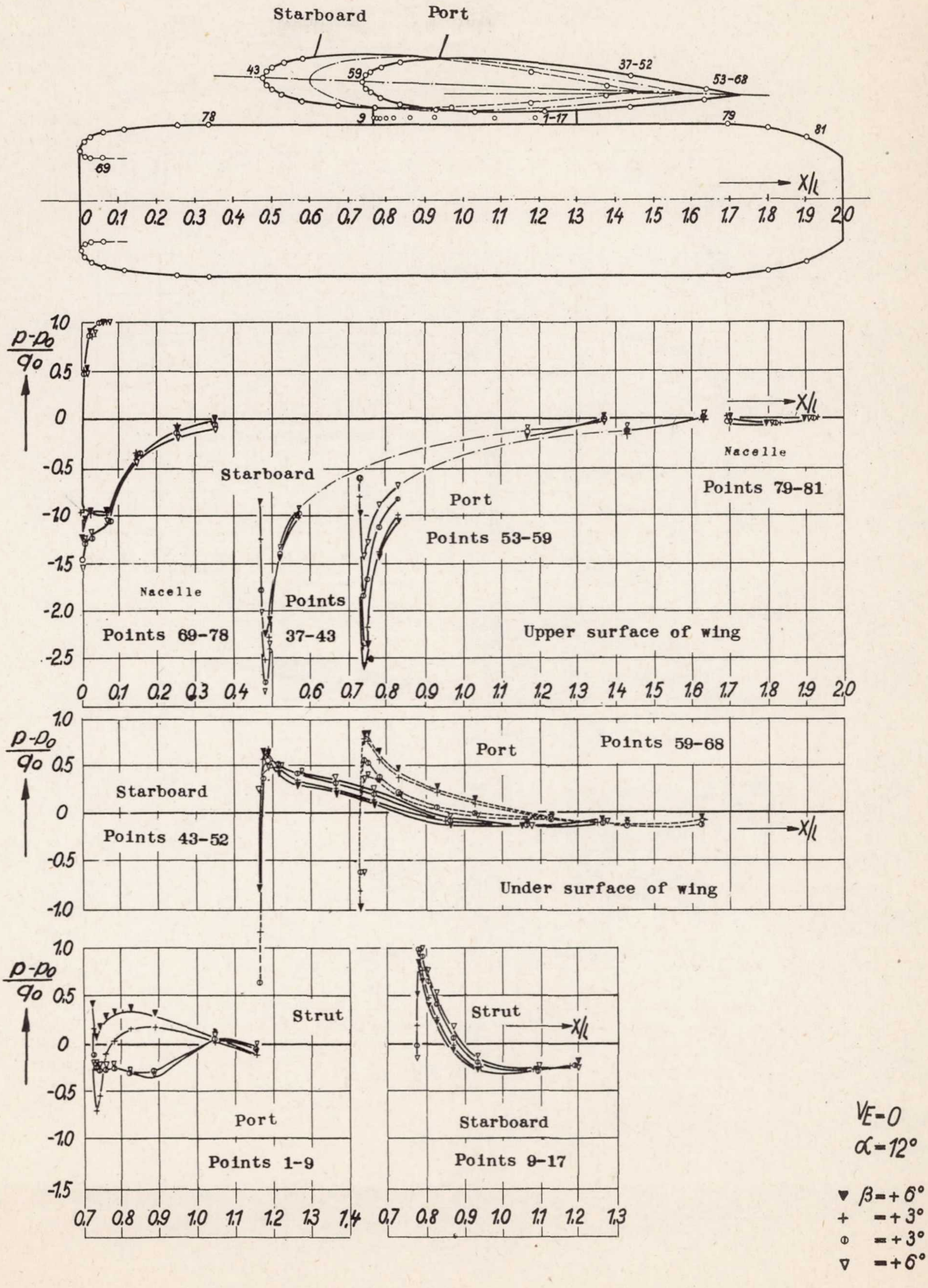


Figure 23.- Arrangement 16; $\alpha = 12^{\circ}$; without through flow.

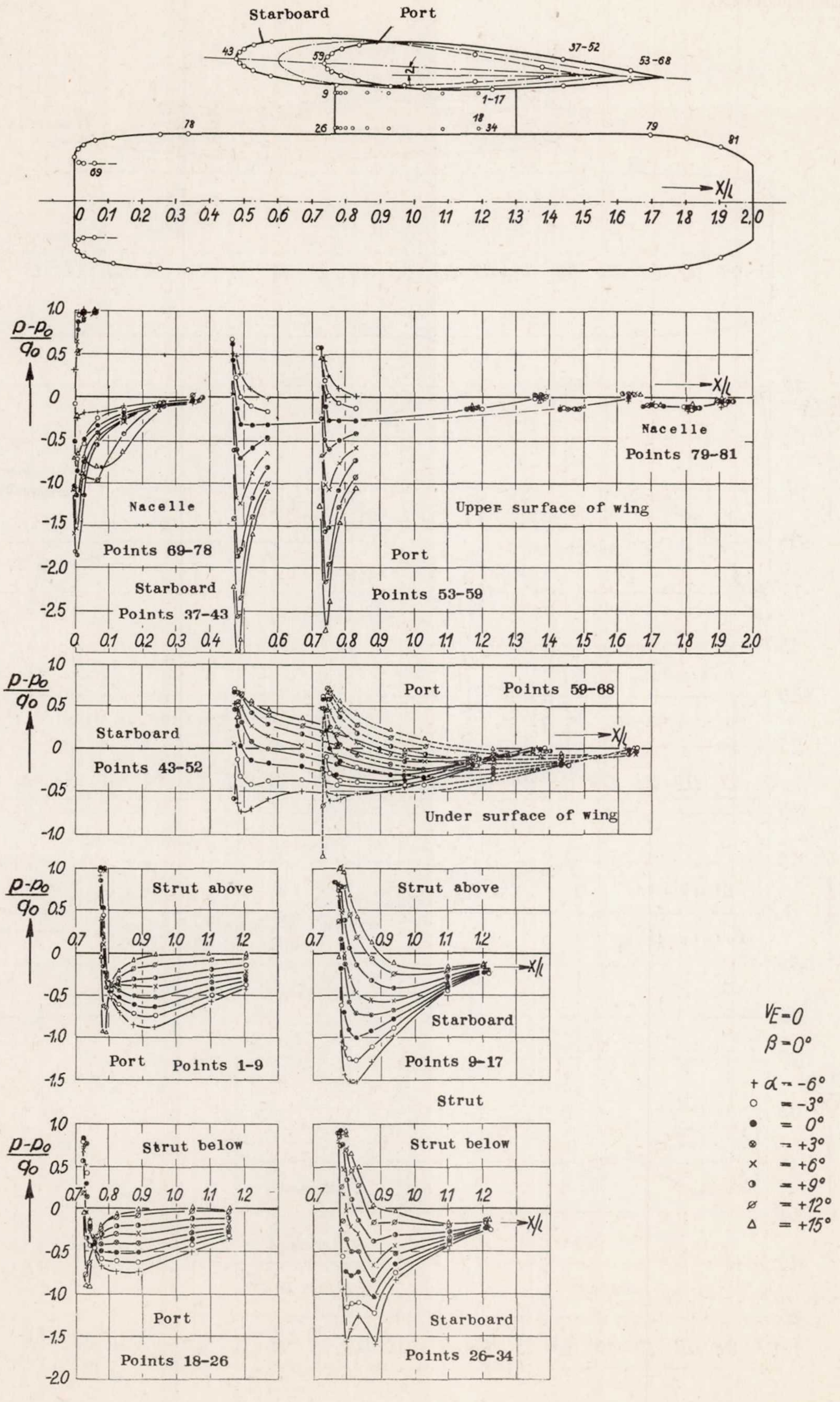


Figure 24.- Arrangement 17; $\beta = 0^{\circ}$; without through flow.

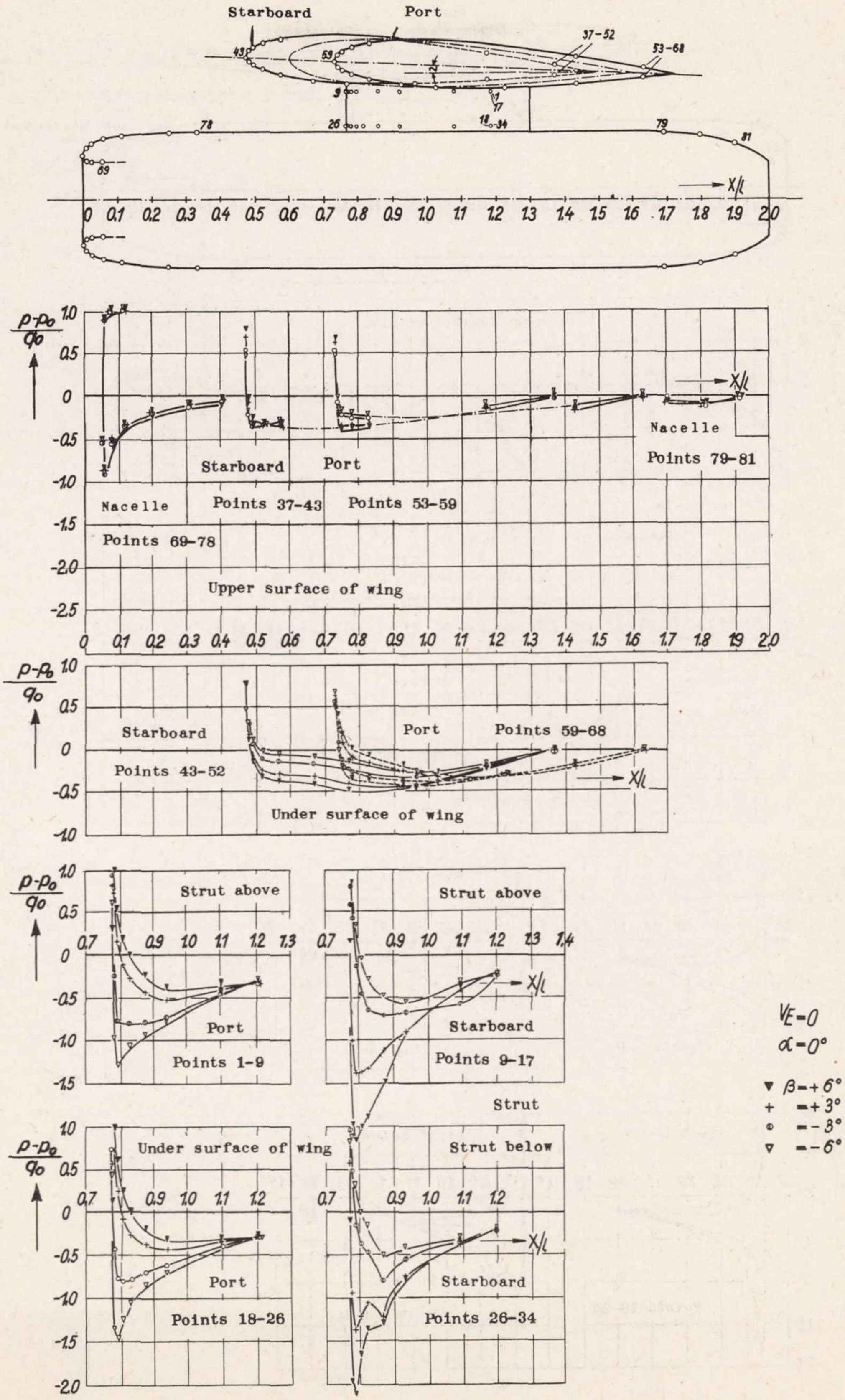


Figure 25.- Arrangement 17; $\alpha = 0^{\circ}$; without through flow.

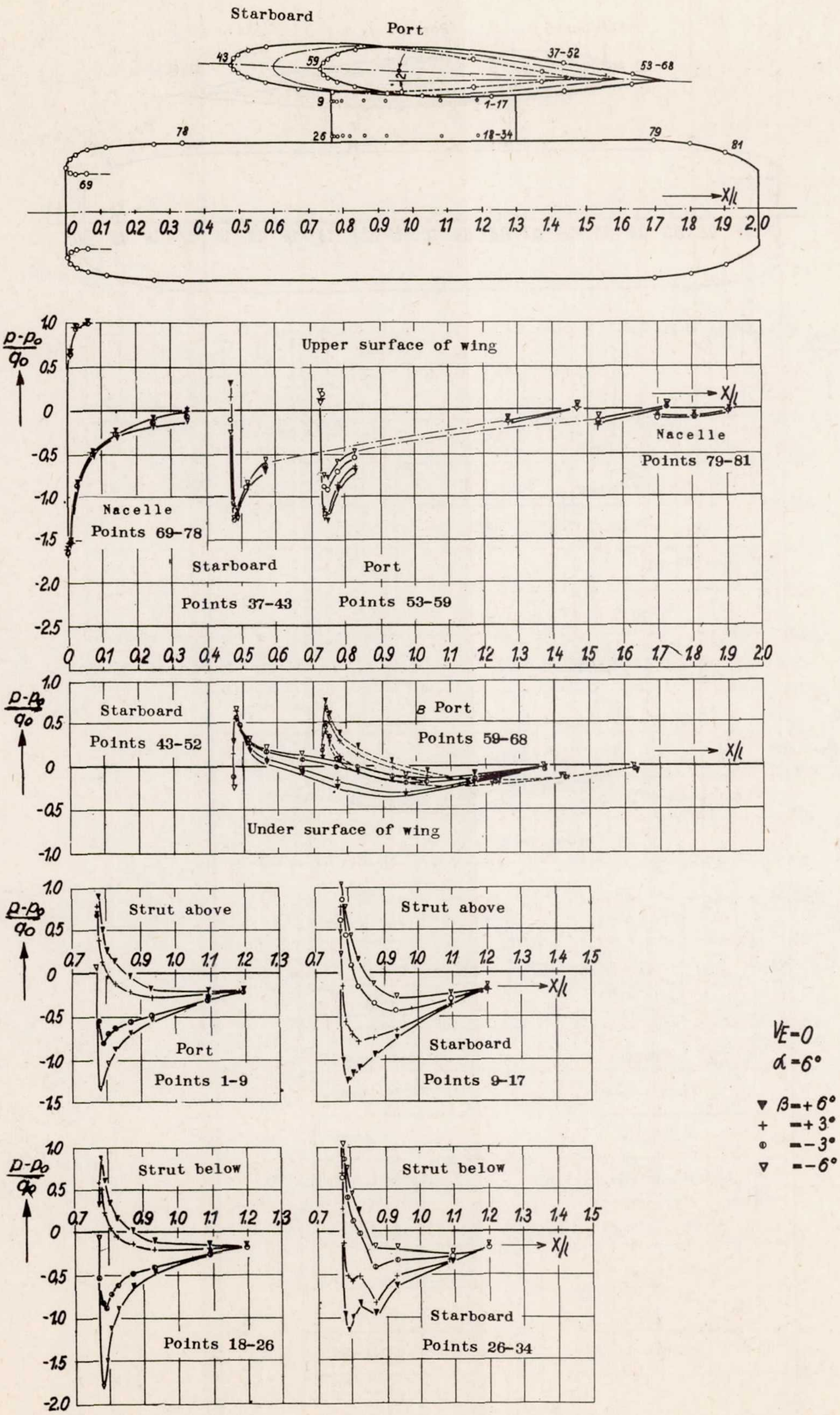


Figure 26.- Arrangement 17; $\alpha = 6^{\circ}$; without through flow.

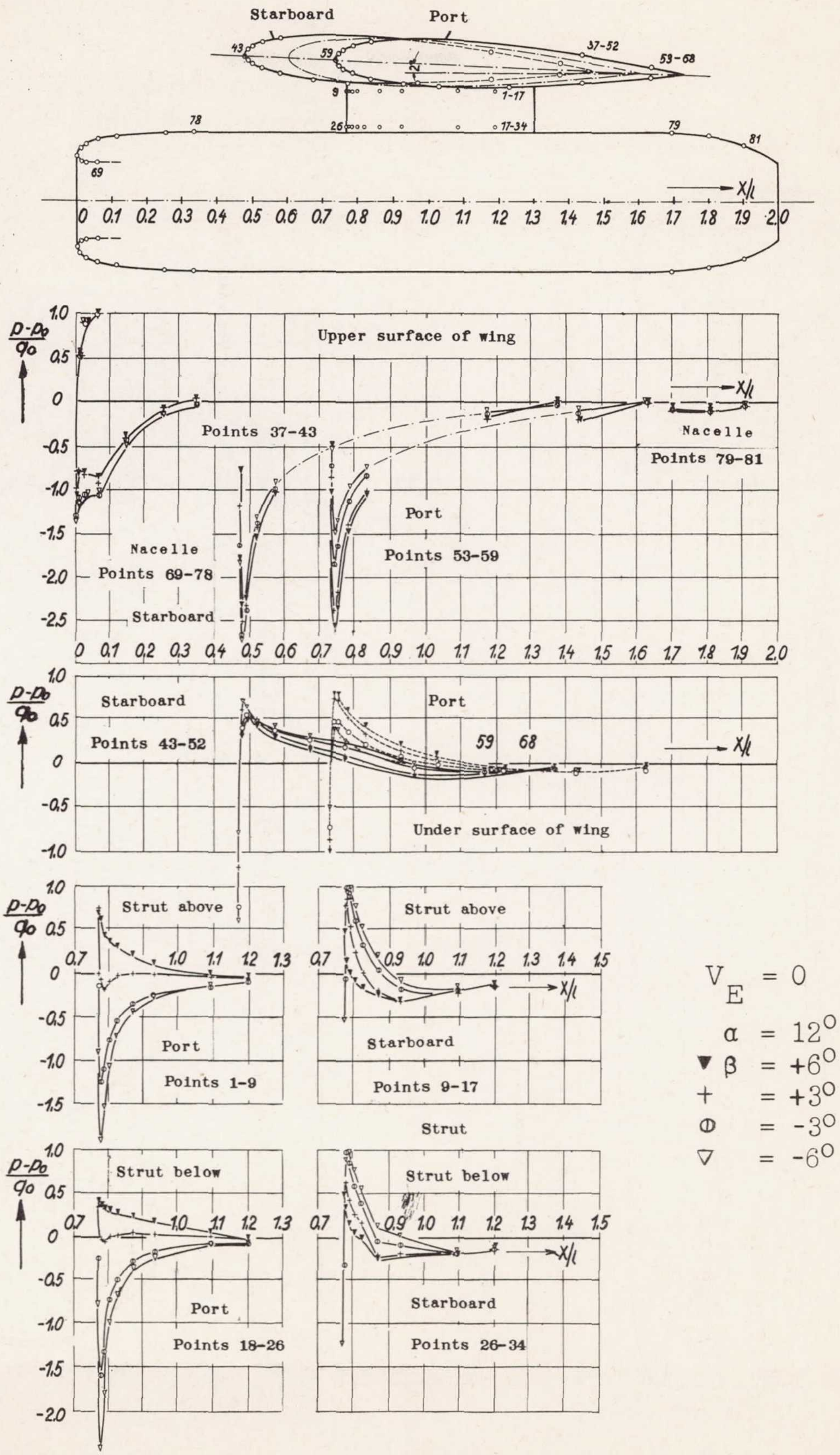


Figure 27.- Arrangement 17; $\alpha = 12^{\circ}$; without through flow.

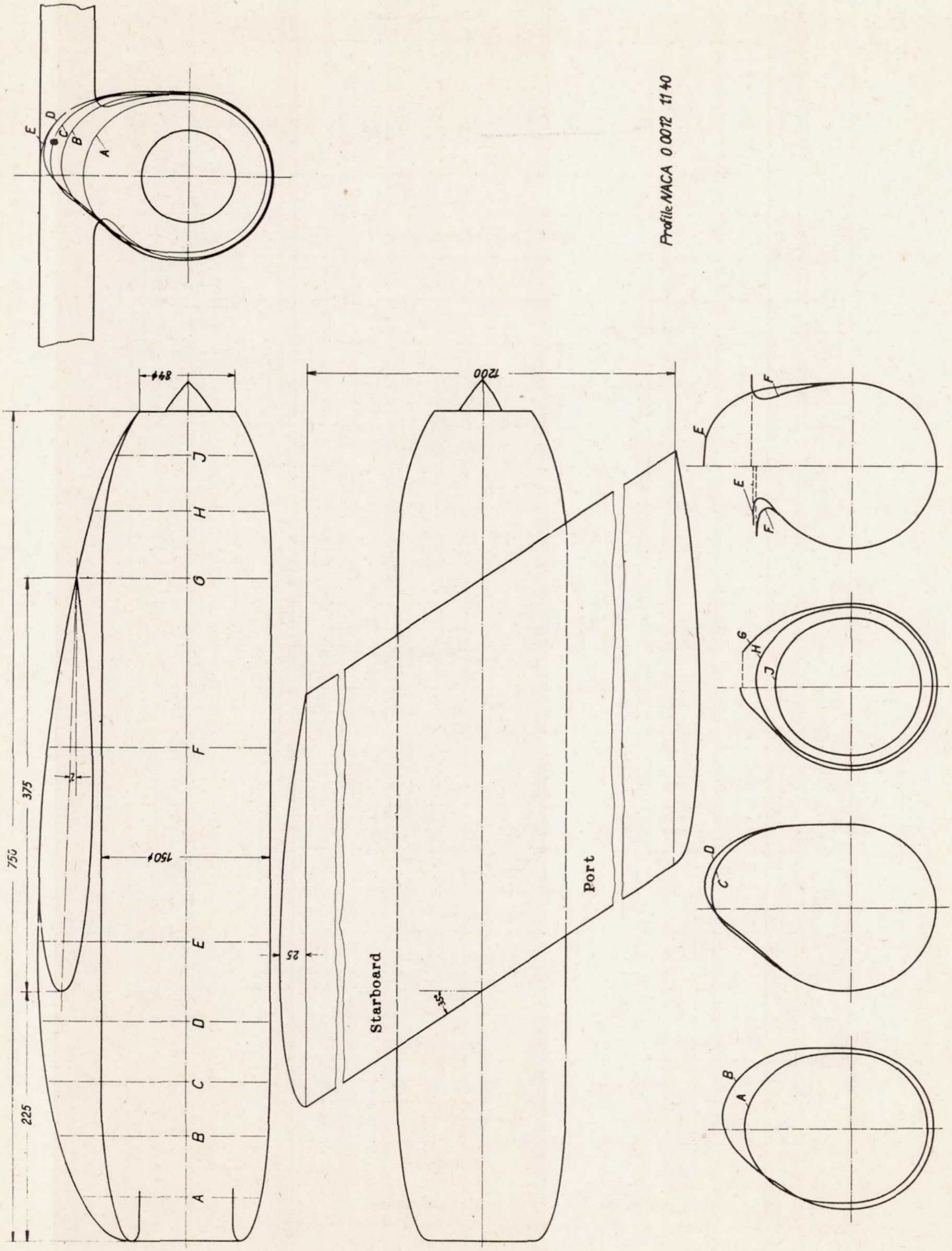


Figure 28.- Arrangement 18; over-all view.

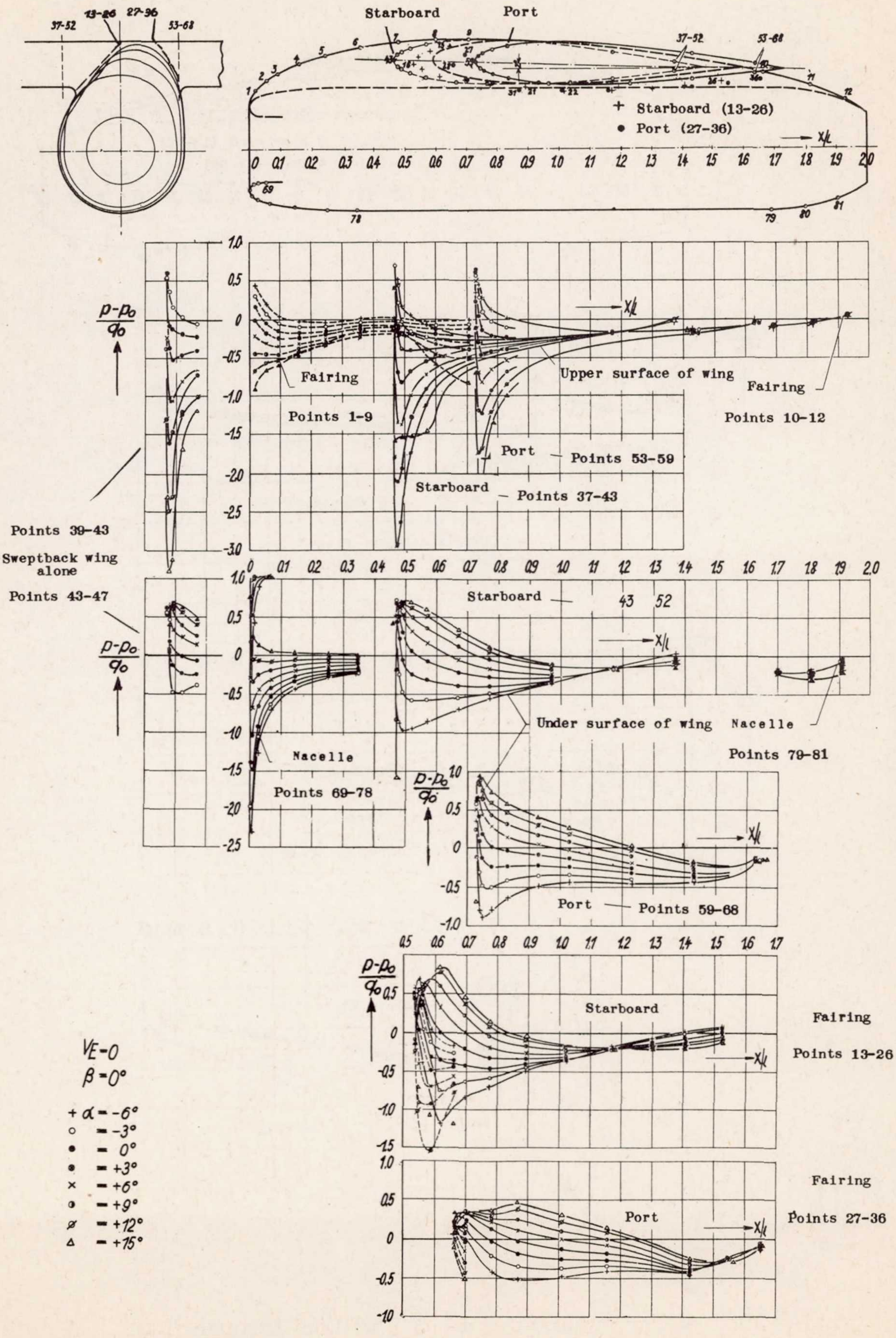


Figure 29.- Arrangement 18; $\beta = 0^{\circ}$; without through flow.

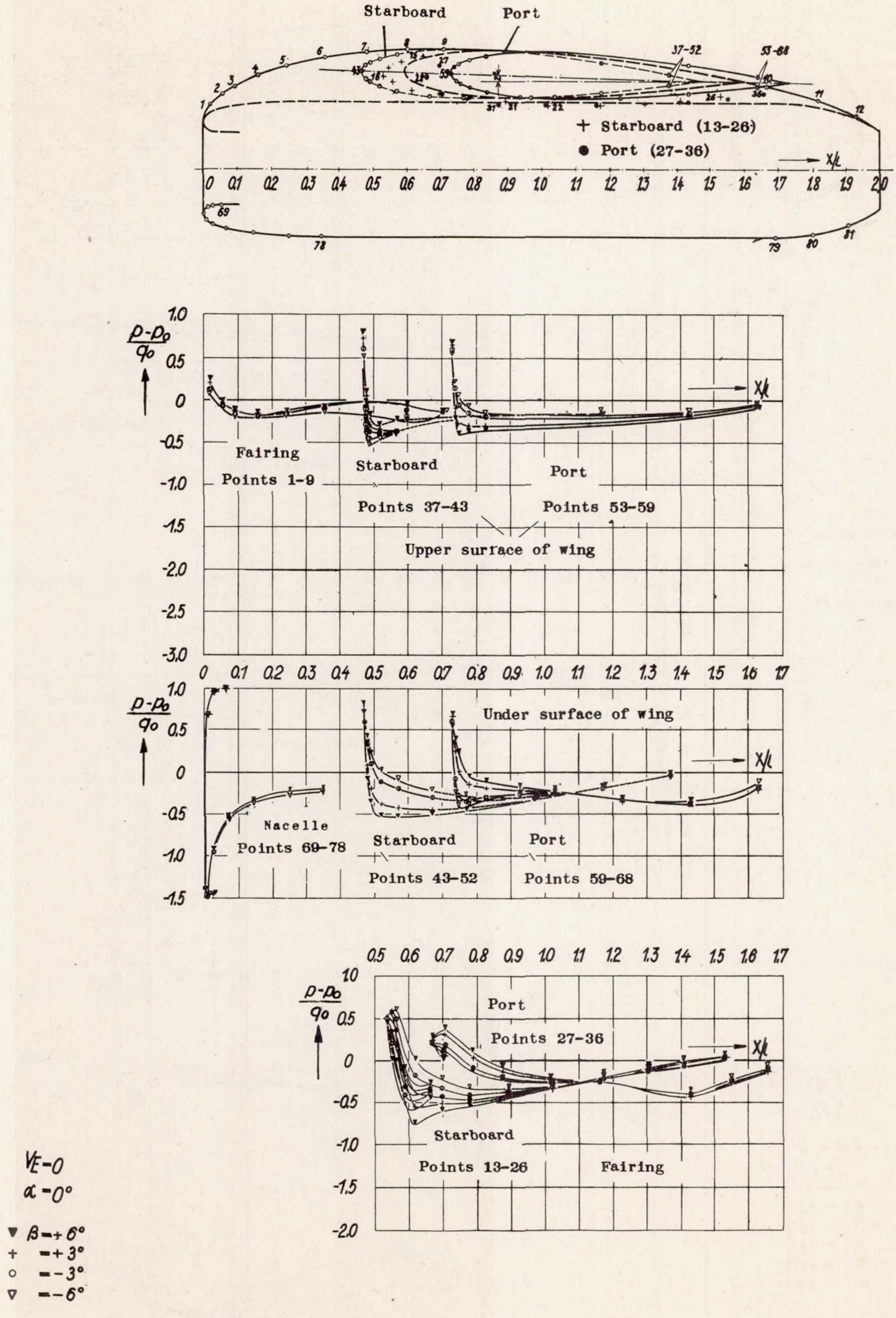


Figure 30.- Arrangement 18; α = 0°; without through flow.

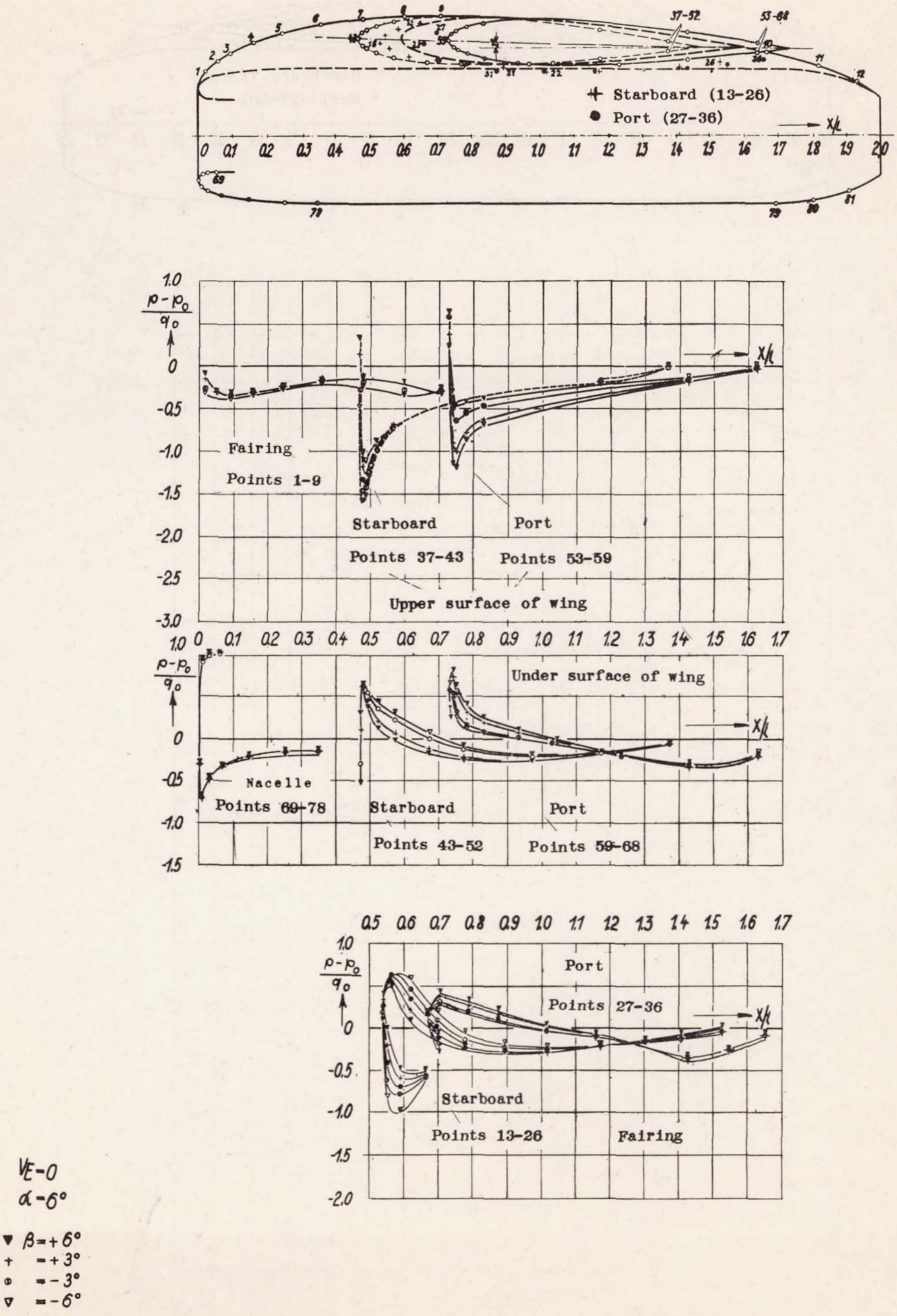


Figure 31.- Arrangement 18; $\alpha = 6^{\circ}$; without through flow.

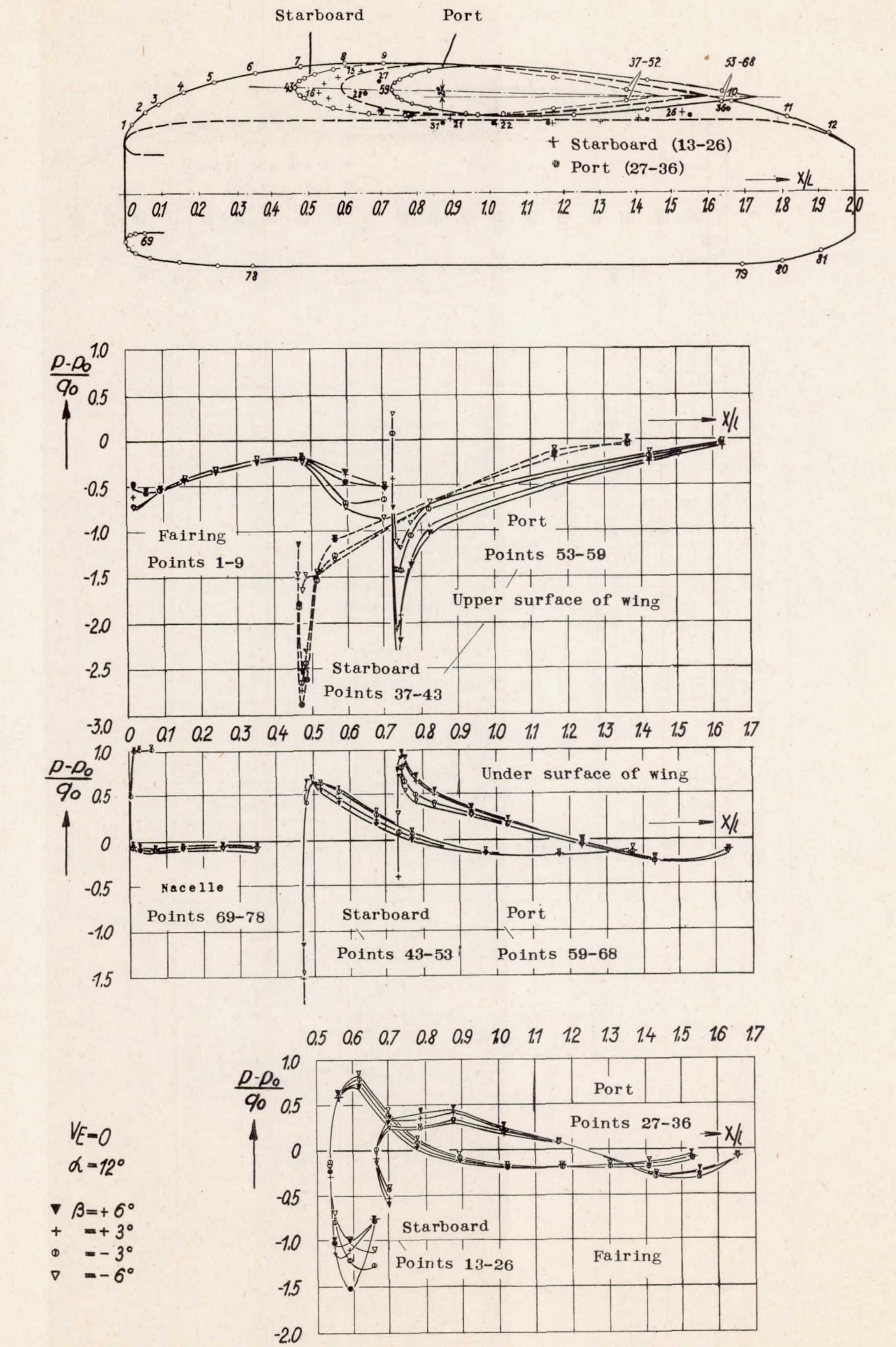


Figure 32.- Arrangement 18; $\alpha = 12^{\circ}$; without through flow.

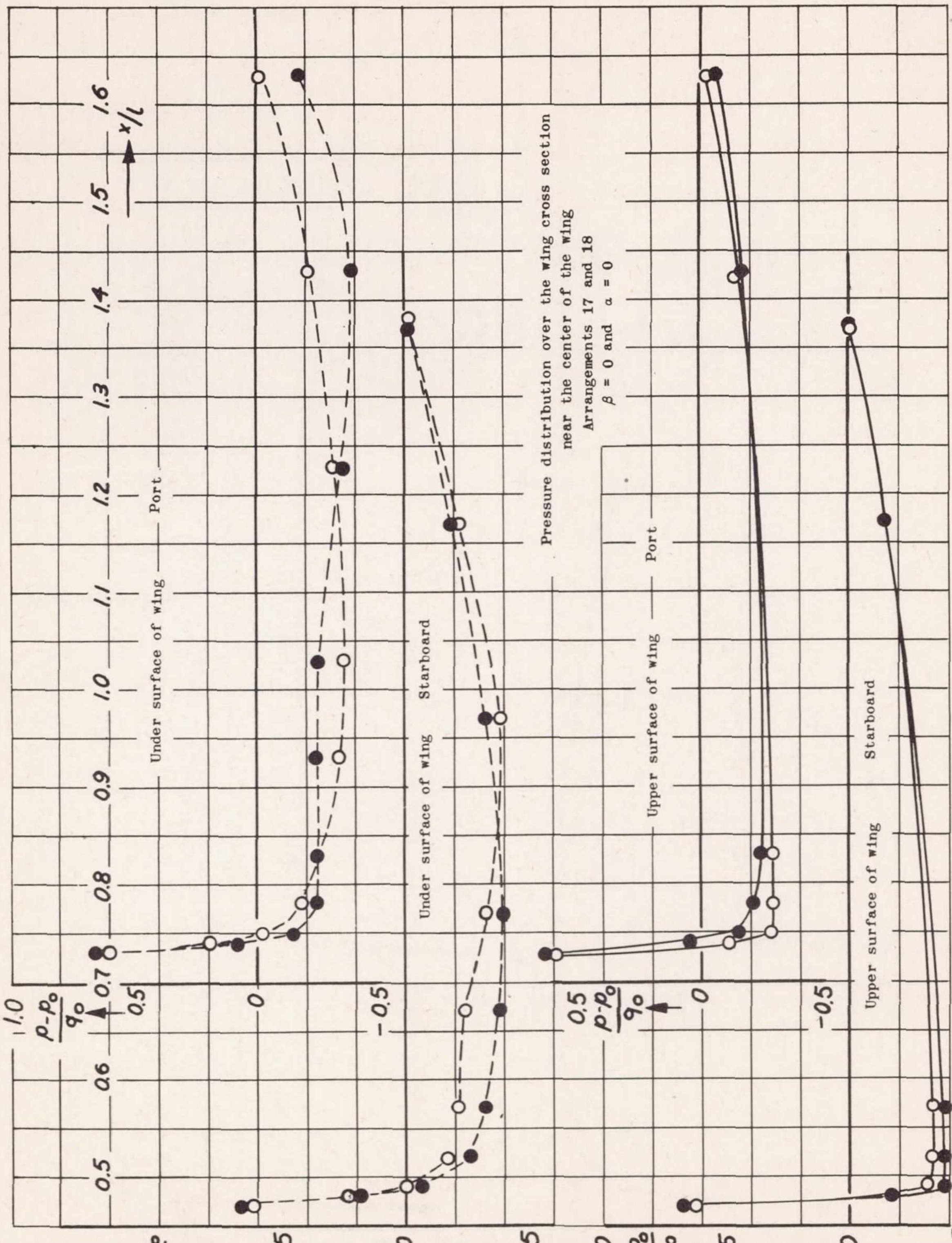


Figure 33.- Arrangement 17, 18; $\beta = 0^{\circ}$, $\alpha = 0^{\circ}$. (Comparison)

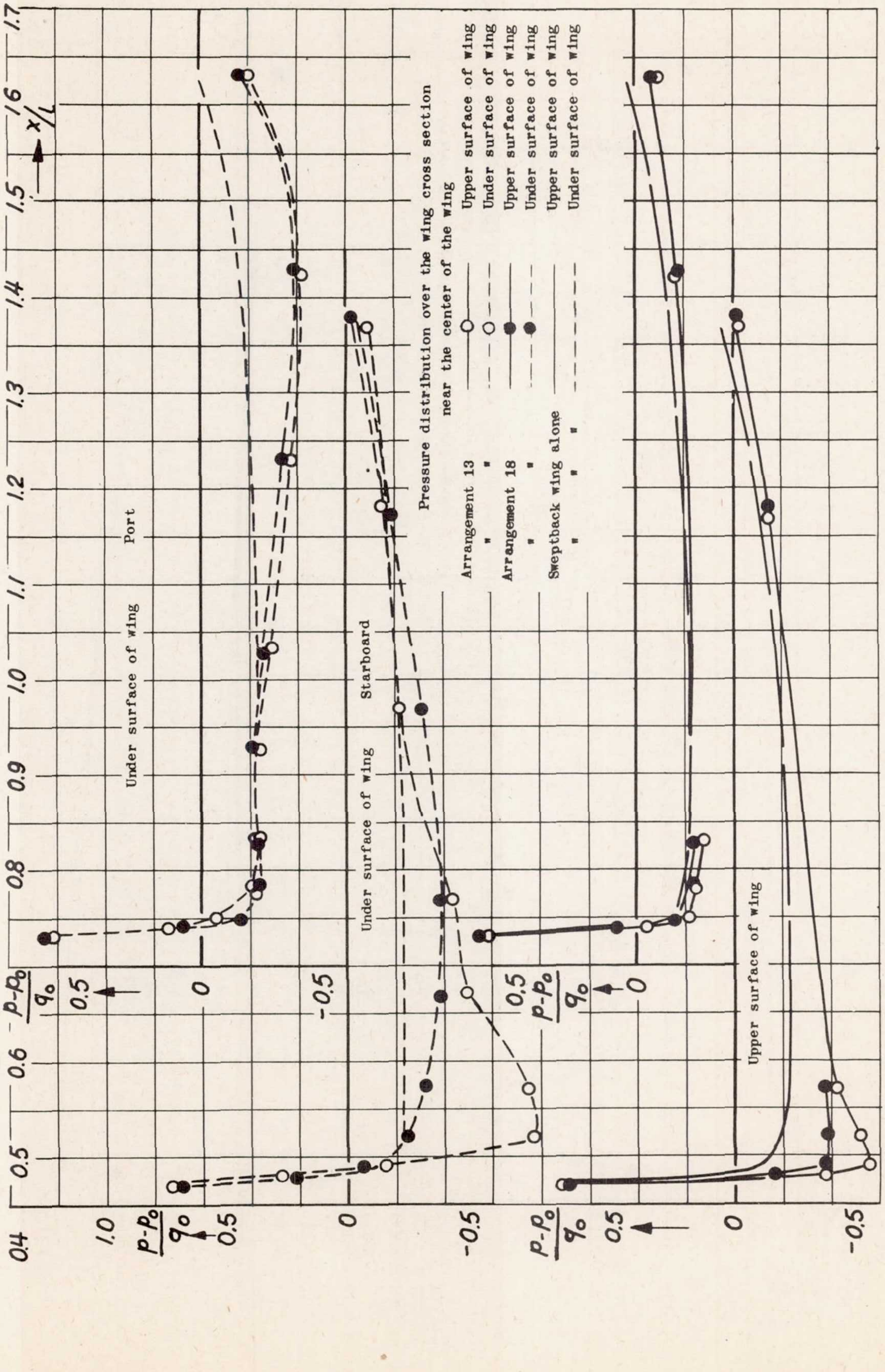


Figure 34.- Arrangement 13, 18; wing alone; $\alpha = 0^\circ$. (Comparison)

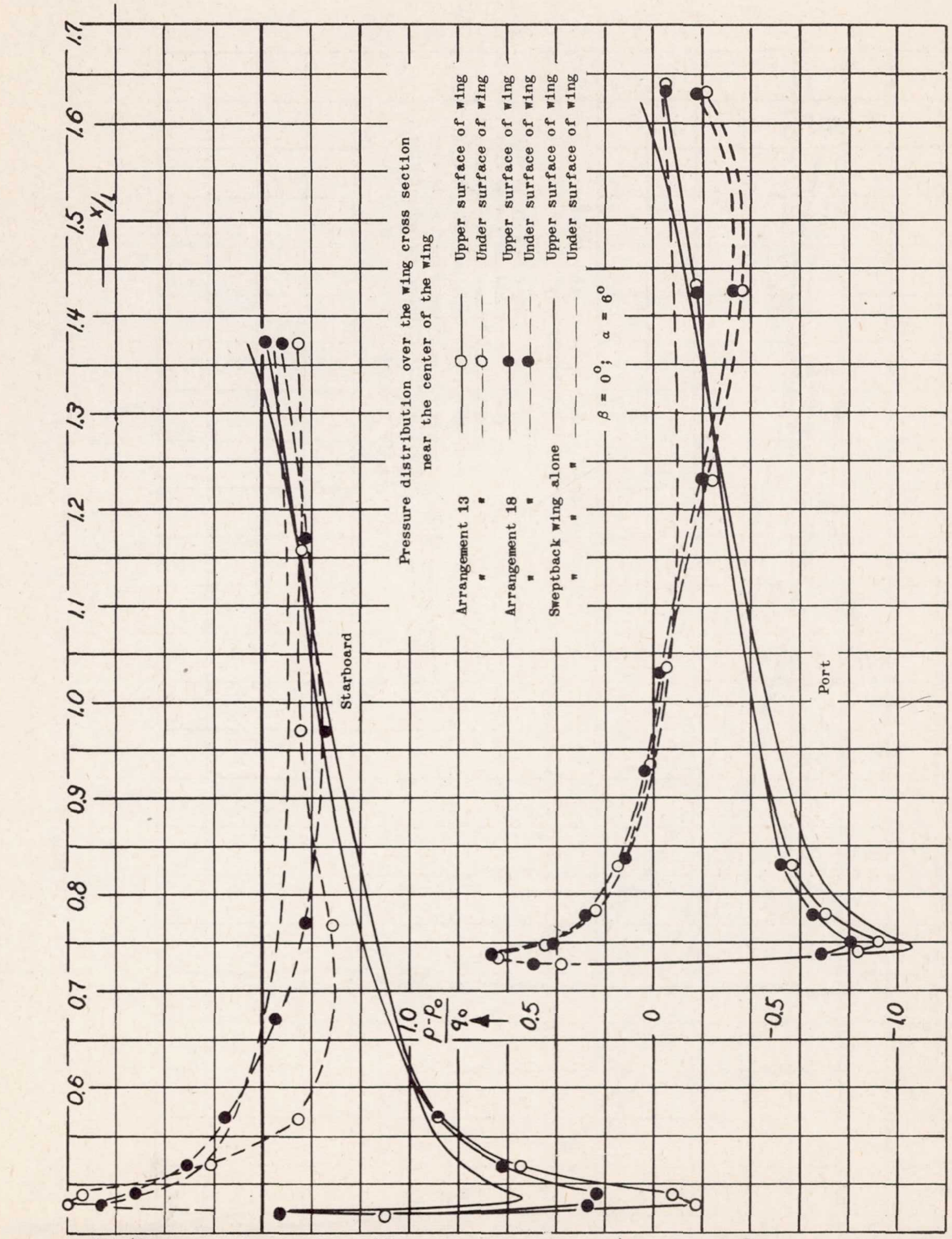


Figure 35.- Arrangement 13, 18; wing alone; $\alpha = 6^o$. (Comparison)

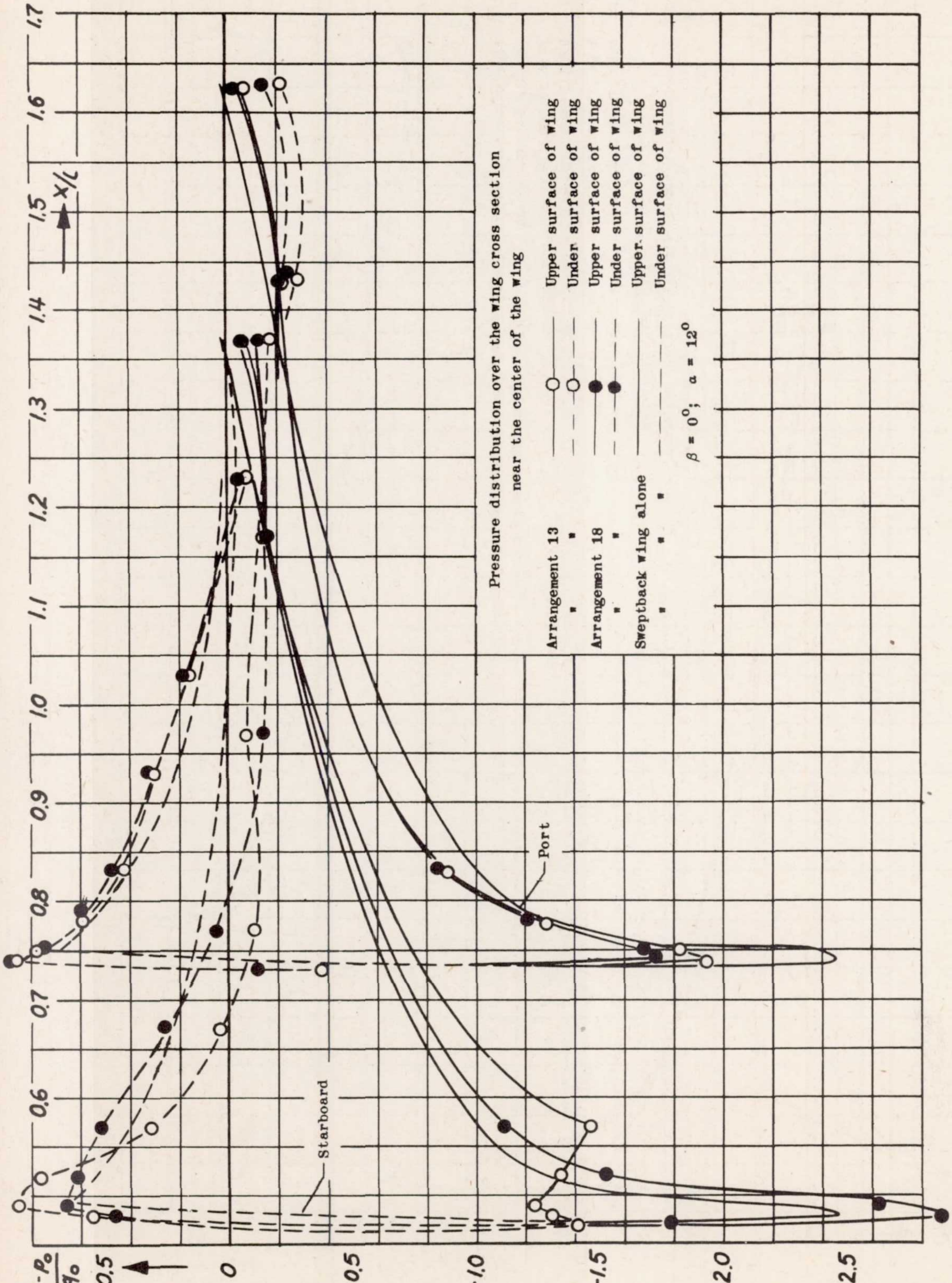


Figure 36.- Arrangement 13, 18; wing alone; $\alpha = 12^{\circ}$. (Comparison)

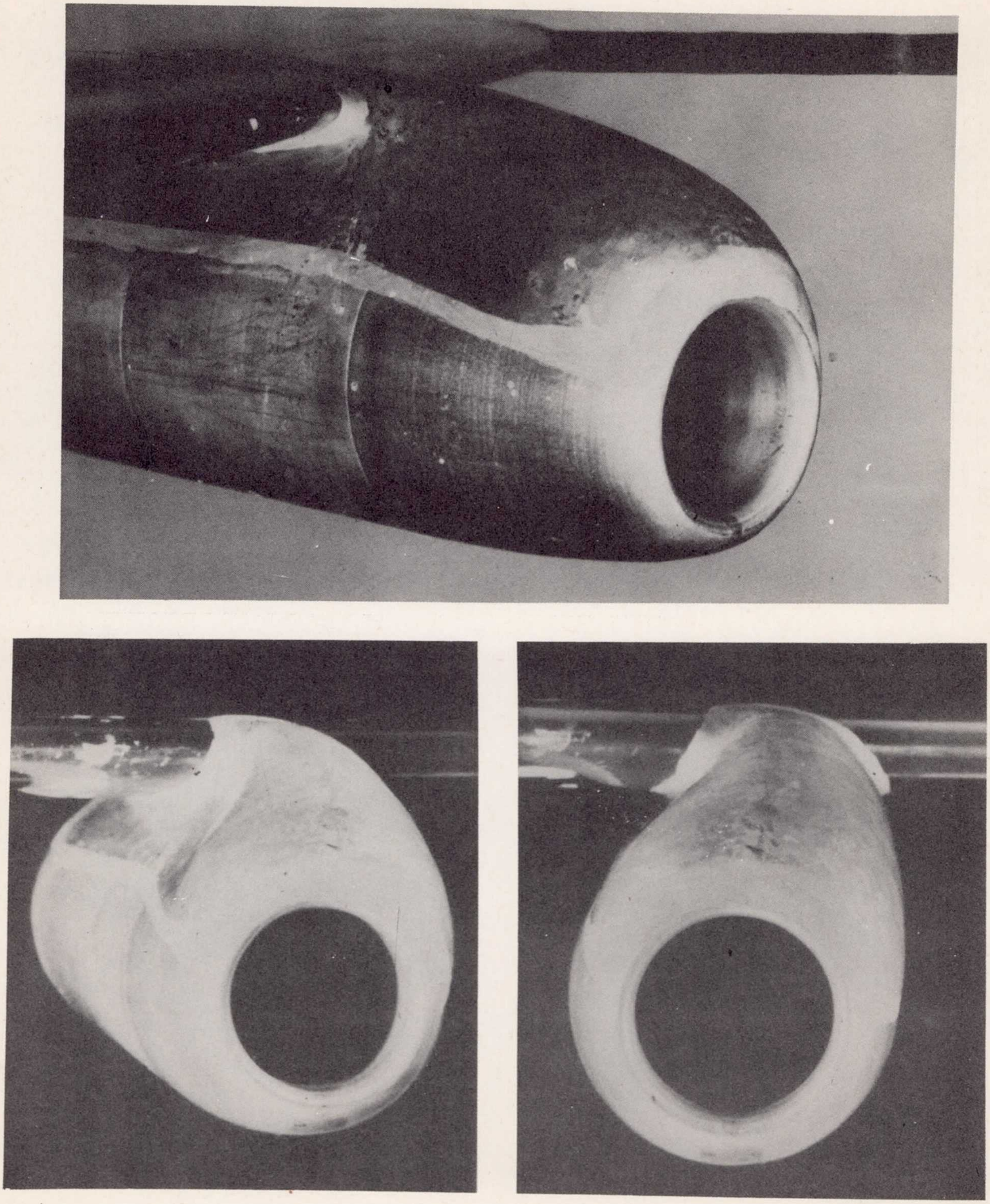


Figure 37.- Arrangement 18; fillet. (Photograph)